SEASONAL ABUNDANCE OF PEST AND BENEFICIAL ARTHROPODS IN RESPONSE TO MANAGEMENT STRATEGIES IN CORN

By

SAUL EDGARDO CONTRERAS GALVEZ

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To my parents,
wife, and
children

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By

Saul Edgardo Contreras Galvez

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The seasonal abundance of certain harmful and beneficial arthropods and nematodes and their response to four pest management strategies were studied in relation to two different planting dates in field corn, in Alachua County, Florida, during 1977-78.

Highest populations of most ground arthropods, nematodes and the two major insect pests, Heliothis zea (Boddie) and Spodoptera frugiperda (J. E. Smith), were recorded at anthesis for both planting dates.

The data suggest that the abundance of species was influenced by weather factors, planting dates, and/or pest management strategies. Weather conditions during preplanting (low temperature and rainfall) and the corn growing season (high temperature and drought) favored fall armyworm outbreaks and reduced the relative importance of the corn

earworm. Late planting favored the build up of damaging pest population levels, regardless of weather factors. Adverse climate and late planting together resulted in a severe pest situation. Low populations of the fall armyworm and corn earworm were recorded under certain management strategies. Nematode populations were probably affected by the drought; however, planting date and pest management strategies had no measurable effect on nematodes. Some species of ground arthropods were affected by the drought and planting date but not by the pest management strategies. The carabid fauna was probably affected by the drought. In general, relatively low numbers of carabids were collected in field corn, regardless of planting date or management strategy. Conoderus spp. and the dermapteran, Labidura riparia (Pallas) were favored by late planting and rainfall.

Yield data from field corn grown under different pest management strategies suggested that the elimination of any needed protective pesticide resulted in higher population of certain pests and a corresponding reduction in yield. Under typical farming conditions practiced in Alachua County, losses ranging from $155.06/ha to $441.42/ha are likely to occur in early and late planted field corn, respectively, as a result of the combined action of the different pests.

CHAPTER I

INTRODUCTION

Corn, Zea mays L., is the largest crop in hectareage grown in the United States. In 1975 and 1976, the total area amounted to 27,196,000 and 28,774,000 hectares, respectively (Anonymous, 1977a). Geographic location and favorable soil conditions have made the United States the largest and most efficient producer of corn. Forty-seven percent of the world's production of corn originates on 23% of the total hectareage planted in corn (Anonymous, 1977a).

In Florida more land is devoted to corn than any other agronomic crop (Westberry, 1975). During the 3 year period, 1974-1976, Florida farmers harvested an average of 198,266 hectares of corn. Eighty-seven percent was exclusively dedicated to corn for grain (Anonymous, 1977b). Preliminary projections for 1978 indicate that 148,000 hectares will be harvested, yielding about 545,115 metric tons (Anonymous, 1978). The expected economic value is estimated at almost 50 million dollars.

The crop is important to the agriculture economy because of the multiple uses of corn and its by-products. Approximately 4% of corn production is used as food for humans, 6% for industrial purposes, and 90% for livestock (Komarek, 1951; Moore and Dwoskin, 1970).

Corn, viewed as food for human consumption, is ranked as the second most important food plant in the world, furnishing about 10 million tons of protein (Mertz, 1970) and constituting the main source of food for some 100 million people (Chiang, 1978). Industrial products of refined corn are starch, sweeteners and feed ingredients (Brenner, 1978). Corn also constitutes the basic raw material for the production of animal protein, milk and other by-products. The consumption by livestock for specific areas of farm production are as follows: hogs, 40.4%; poultry, 19.3%; beef cattle, 15.9%; and dairy cattle, 13.7% (Moore and Dwoskin, 1970).

World food shortage has prompted efforts to increase corn yields. The introduction of hybrid corn in 1930 brought about a three-fold yield increase in 25 years (Sprague, 1975) as well as improvement in the biological value of corn protein (Chou et al., 1977).

In addition to genetic factors, corn productivity is limited by climatic conditions, soil fertility, and pests. The major corn producing areas are those located between latitudes of 30 to 55 degrees, having relatively warm weather and annual precipitation from 25-500 mm. However, corn, because of the genetic variation may be grown under a wide range of environmental conditions (Shaw, 1977).

Fertilizers have a preponderant role in corn productivity. Properly fertilized plants may have 30% more kernels, an

increase of 50% in ear weight, twice the amount of carotene, and enhanced power to withstand the action of environmental factors (Chou et al., 1977).

Crop protection is primarily by the use of synthetic organic chemicals. Herbicides provide an environment relatively free of competitors that, in addition to the effect of competition, may be the main or alternate host for pathogens and insects (Klingman et al., 1975). Large quantities of herbicides are used on corn. Fifty percent of the total farm consumption (80% of the total U.S. consumption) of herbicides is used on corn (Chou et al., 1977).

Insecticides are needed to protect the crop and maintain productivity levels. These chemicals enable the farmer to reduce numbers of a wide range of insect pests and provide crop protection from grain seeding to grain bin (Brinkley, 1972). Insecticide usage has been substantially decreased through breeding programs. For many years, corn breeders have been developing insect-resistant varieties (Collins and Kempton, 1917) and resistance to 17 species of corn insects has been studied (Painter, 1968). In the Southern United States considerable research has focused on the corn earworm, Heliothis zea (Boddie) (Wiseman et al., 1976; Wiseman et al., 1977).

In spite of the genetic improvements, large amounts of insecticides are still used on corn. Of the total U.S. production of insecticides, 70% is used on farms. Tobacco

and soybean receive 2% each, corn 18% and cotton 50% (Chou et al., 1977).

Assessment of losses due to pest attack is a crucial phase of today's agriculture. Worldwide annual losses of 30% of potential yield occur despite the use of advanced farming technology and mechanized agriculture (Ennis et al., 1975). Studies of real losses are needed for the implementation of pest management systems (Chiarappa et al., 1972). Data are required on the numbers of a pest present and its biology, distribution in area and time, and the relationship between pest activities and yield (Walker, 1975).

The estimation of pest losses in field corn is an important but difficult problem. Studies indicate that, economically speaking, corn is an inelastic crop with a relatively narrow margin of profit (Chiang, 1978). Shortages of soil moisture are not uncommon (Westberry, 1975). Most threholds for corn pests are still lacking (Turpin, 1974a). Changing varieties, agronomic practices, insect populations, control programs, and market values can all alter the economic relationship among insect species and between these species and the crop (McMillian et al., 1976). In general, little is known about some corn pests that, although not always taxonomically related, act together as a group of organisms rather than as single species, occupying similar niches and which may or may not cause similar injury. These circumstances make extremely difficult any determination of key pests that are responsible for yield reduction. This information is

needed as an important component in the establishment of a crop protection program for managing a field corn production system.

Research was undertaken in 1977-78 to investigate certain aspects of the life system of corn relative to pest management and crop protection. Specific objectives were to determine the

1. seasonal abundance of the corn earworm, Heliothis zea (Boddie), and fall armyworm, Spodoptera frugiperda (J. E. Smith), in early and late planted corn,
2. seasonal abundance of nematode genera associated with field corn,
3. beneficial and harmful ground arthropods in corn fields,
4. nature and extent of damage caused by specific pests,
5. response of certain components of the corn system to different management strategies.

CHAPTER II

FALL ARMYWORM, Spodoptera frugiperda (J.E. SMITH), AND CORN EARWORM, Heliothis zea (BODDIE), POPULATION LEVELS AND DAMAGE IN EARLY AND LATE PLANTED FIELD CORN, IN ALACHUA CO. FLORIDA

Introduction

The major insect pests of field corn in Florida are the corn earworm, Heliothis zea (Boddie), and the fall armyworm Spodoptera frugiperda (J. E. Smith) (Johnson, J. T. et al., 1974).

Both the corn earworm and the fall armyworm are long-standing agricultural pests. The corn earworm was rated as the third most important pest in the United States (Hyslop, 1927); the fall armyworm was also listed as pest of major economic importance (Luginbill, 1928). Both damage corn as well as other crops and cause considerable loss (Bishop, 1917; Walton and Luginbill, 1916; Luginbill, 1928; Dicke, 1939). Life histories of the two insects are similar; both exhibit cannibalistic behavior and are preyed upon by many of the same species of predators (Luginbill, 1928; Barber, 1936; Ditman and Cory, 1931).

The fall armyworm and corn earworm feed on leaves, whorls, tassels, and ears (Luginbill, 1928; Morrill, 1971). Both feed in furls and make holes through the tightly bunched

leaves. Feeding by the young larvae results in skeletonized leaves; late instars can stunt or kill young plants by consuming all but the leaf midribs and stalks of older plants (Luginbill, 1928; Vickery, 1929; Blanchard and Douglas, 1953; Wiseman et al., 1967a).

Foliage destruction results in decreased yield (Morrill, 1971). Insect damage is a function of plant density (Widstrom, 1969), edaphic factors (Turpin et al., 1972), pest population density, corn variety and plant growth stage (Kelsheimer et al., 1950). Defoliation occurring at late whorl or early tassel stages (Kiesselbach and Lyness, 1945) as well as from tassel to silking (Prine, 1962) reduces yield. Yield reduction is not directly proportional to the destroyed leaf area; however, foliage losses of 25, 50 and 100% resulted in 8, 23, and 94% yield reduction (Morrill, 1971). Removal of the topmost five leaves decreased grain yield by 20% (Prine, 1962).

Population studies of the corn earworm indicate that the insect appears during the spring, with high numbers observed from June through August (Gentry et al., 1971; Snow et al., 1972). Similar studies have determined that the fall armyworm is active from April through October (Snow and Copeland, 1969; Tingle and Mitchell, 1977). These conclusions are based on moth trapping, but few reports deal with crop phenology and the incidence of both pests (Morrill, 1971; Johnson, M. W. et al., 1975). Seasonal population dynamics of insect pests are important to integrated pest management. Reliable

estimates of pest population densities are needed to select the best control strategies (Gonzalez, 1972).

Cultural practices are the manipulation of the environment to improve crop production (Thompson, 1975). Planting date is a very important cultural practice in field corn production. Early planting reduces levels of pest infestation and increases corn yield (McColloch, 1924; Everly, 1961).

The study here reported was conducted to determine population levels of the fall armyworm and corn earworm in early and late planted corn and to evaluate damage resulting from leaf feeding of these insects.

Materials and Methods

Experiment 1. A 4.8 ha commercial field of corn about 5 km west of Gainesville was surveyed weekly to determine the population levels of the fall armyworm and corn earworm, or seasonal abundance. Coker 77 hybrid corn was planted March 6, 1977. The soil was partly characterized as fine sand sparr variant and the rest as fine sand lochloosa series (Standard Soil Survey Alachua County, Florida, 1978). Both had similar properties, although in the lochloosa series, the surface and subsurface layer are about 71.12 cm thick and in the sparr variant, 147.32 cm. Soil pesticides applied were carbofuran at a rate of 1.12 kg ai/ha and alachlor at 3.3 kg ai/ha. The entire field was fertilized with 10-10-30

at a rate 337 kg/ha and two sidedressings of anhydrous ammonia at 112.2 kg/ha, each.

The sampling was initiated when the corn was in the three leaf growth stage and continued through maturity. The corn field was divided into five sites, each about 9600 m^2. The sampling unit was the corn plant (Hudon and LeRoux, 1961). At each site, 50 consecutive plants, or its equivalent 10 m of row, were sampled along the row on two adjacent rows to make 100 plants/site or 500 for the entire field (Harris, 1958). The numbers of fall armyworm and corn earworm larvae were recorded and expressed as number/10 m of row. Samples were taken at weekly intervals from March 16-July 13, 1977.

Growth stages of corn were observed and recorded on each sampling date. The stages were determined by comparing the actual plant growth with those illustrated in a corn growth stage key (Hanway, 1971).

Plant damage due to fall armyworm and corn earworm feeding activities was evaluated by comparing actual damage with those ratings in Ashley's damage scale (T. R. Ashley, Personal communication). The damage scale is as follows: "0 - no visible damage. 1 - slight; pinholes, shot-holes, small lesions. 2 - moderate; less than 50% of the leaves with lesions or leaf sections eaten away. 3 - heavy; greater than 50% of the leaves with lesions or sections eaten away. 4 - severe; whorl destroyed to the point of retarding plant; no tassel formed." Plant damage was evaluated when the corn plant reached the tassel stage.

Tassel damage was evaluated by comparing the lengths of injured and uninjured tassels to determine length destroyed. Damage was rated as follows: 0 - no visible damage. 1 - less than 25% eaten. 2 - from 25 to 75% eaten. 3 - more than 75% eaten away.

Climatological data during the study period were those recorded for Gainesville (Table 34 and 35).

Experiment 2. The influence of the fall armyworm and corn earworm was studied in 1977 in a 7.9 ha commercial field of corn located 24 km west of Gainesville. The soil was a fine sand lochloosa series (Standard Soil Survey Alachua Co. Florida, 1978). The corn hybrid was McNair 508, planted April 10. The distance between plants was irregular, but on the average, there were 6 plants/2 m. The rows were 100 cm apart.

The soil was treated with butylate + atrazine at a rate 3.36 + 2.24 kg ai/ha, and carbofuran at 1.12 kg ai/ha. The entire field was fertilized with 337 kg/ha of 10-10-30 and a subsequent sidedressing of ammonium nitrate with 112.2 kg/ha. Observations were made at weekly intervals from April-August, 1977.

The sampling was begun when corn was in the 3-leaf stage and continued through maturity. The corn field was divided into five sampling sites, each about 15390 m^2. The basic sampling unit was the corn plant (Hudon and LeRoux, 1961).

The methods were as described in experiment 1 except that at each site, the number of plants in 10 meters of row was sampled along the row. The sampling was repeated four times in alternate rows to make a total of 40 m-row per site. Owing to excessive corn earworm and fall armyworm infestations, the sampling was reduced to 8 m-row per site when corn reached the tassel stage. The observed number of fall armyworm and corn earworm was recorded and expressed as number/2 m-row.

Tassel damage was rated as follows: 0 - no visible damage. 1 - less than 25% eaten. 2 - from 25-50% eaten. 3 - from 50-75% eaten. 4 - with more than 75% eaten away.

Numbers of corn earworm and fall armyworm per plant were also recorded during posttassel growth stages. Six categories were established as follows: 0, 1, 2, 3, 4, and 5 or more larvae per plant. In addition, fall armyworm and corn earworm ratios as well as the number of larvae infesting the upper and lower ear were determined.

Corn stalk breakage was also recorded. Two levels of damage were established as follows: corn stalk broken above or below the position of the upper ear. Shank damage was evaluated by determining the number of dropped ears per 8 m0row.

Experiment 3. The research was conducted at Green Acres, University of Florida Experimental Station, during the spring

and summer, 1978. The materials and methods apply to both early and late planted field corn. The soil was characterized as fine sand lochloosa series (Standard Soil Survey Alachua Co. Florida, 1978). The hybrid Coker 77 was planted April 5 and McNair April 28, respectively. In both plantings, the distance between plants was 20 cm in rows 91 cm apart. Both fields were fertilized before planting with 4-8-16 at 785.63 kg/ha and one sidedressing of ammonium nitrate at 112 kg/ha thirty days after planting.

A randomized block design was used for each planting date laid out over an area of 3416.64 m^2. Early planted field corn consisted of four treatments, each replicated four times. Each replicate was 8.80 x 12.12 m^2. Late planted corn also had four treatments but replicated three times. Each replicate was 10.92 x 12.12 m^2.

The treatments, hereafter called strategies, were as follows:

Strategy A. To control weeds and the complex of Heliothis-Spodoptera with pesticides. No treatment was made for soil pests. Atrazine at 1.12 kg ai/ha was applied postemergence 10 days after planting and before the corn was 12.7 cm tall. Methomyl, 0.5 kg ai/ha, was applied as needed to control Heliothis-Spodoptera.

Strategy B. To control soil pests and Heliothis-Spodoptera but not weeds. The soil was treated with carbofuran at 2.24 kg ai/ha. Methomyl, at the above rate, was applied as needed.

Strategy C. To control weed and soil pests but not Heliothis-Spodoptera. The pesticides, rates, and application time were those mentioned above.

Strategy D. To control weeds, soil pests and Heliothis-Spodoptera using the recommended pesticides. The rates, application time, and frequency were as described.

Methomyl was applied to individual plants and the spray directed toward the whorl. Ear treatments consisted of spraying silks, husk and all parts surrounding the ears. Both whorl and ear were sprayed until thoroughly covered and the insecticide ran off. Effectiveness of insecticide application was checked 24 hours after treatments. No preventive methomyl applications were made. All applications were based on corn earworm and fall armyworm infestation levels determined prior to the treatment. Methomyl treatments were initiated May 12 and 26, in early and late planted corn, respectively. The applications were continued throughout the corn growing season until no further pest infestation was recorded.

Fall armyworm and corn earworm were monitored weekly to determine infestation levels in early and late planted corn. The surveys were conducted on plots untreated with methomyl, strategy C. On each sampling date, 400 and 300 corn plants were examined to determine infestation levels in early and late planted corn, respectively. The infestation level was recorded, tabulated, and expressed as percentage. Similar surveys were conducted on methomyl treated plots,

strategies A, B, and D. These plots were sampled twice a week, however, or as needed prior to and after methomyl treatments.

Plant damage from fall armyworm infestations occurring during pretassel stages of corn growth was established by using a damage rating scale provided by T. R. Ashley (Personal communication). Ashley's scale applies the ratings to individual plants and determines damage according to five levels. The scale was modified to apply the same ratings to individual leaves as to plants. The modified scale is as follows: 0 - no visible damage. 1 - Slight; pinholes, shot-holes, small lesions. 2 - Moderate; leaves with less than 50% eaten away. 3 - Heavy; leaves with more than 50% eaten away. 4 - Severe; leaf completely destroyed. One hundred plants from untreated methomyl plots, strategy C, were rated to determine leaf damage. On each plant, 16 leaves, from top to the bottom, were rated according to the modified scale. The individual ratings were recorded and the frequency distribution determined. Leaf damage was evaluated when corn reached the tassel stage. At that time the leaves were completely unfolded and the damage could easily be determined.

Results

Seasonal Abundance

Results from surveys conducted in 1977 to determine the seasonal abundance of the fall armyworm and corn earworm in field corn, Coker 77, planted March 6 are shown in Figure 1. Neither species predominated throughout the study period. Fall armyworm population levels were higher than those of the corn earworm from mid-whorl through the tassel stage. Population of both species peaked almost simultaneously, declined as corn progressed toward the tassel stage and remained at low or zero densities during silking and blister stages. Thereafter, the corn earworm was the dominant species. Highest numbers occurred at the beginning of corn dent stage. A rapid decline occurred after highest population levels were observed. During this period, the fall armyworm was less abundant than the corn earworm. However, the fall armyworm population maintained an increasing trend. Declining trend in corn earworm numbers coincided with an increase in larval numbers of fall armyworm.

In late planted field corn, McNair 508, the fall armyworm infestation began in the corn plants during the early-whorl stage of growth and continued throughout the entire growing season (Figure 2). Relatively high numbers of fall

armyworm larvae were recorded during all stages of ear development. Posttassel infestations were considerably higher than those observed during whorl stages. The corn earworm population built up during corn silking and reached a peak during the blister stage. These high numbers were never as high as those of the fall armyworm. Both species population trends were more or less similar. However, the corn earworm population peak coincided with a slight fall armyworm population decline (Figure 2).

Multiple infestation of plants by the fall armyworm (Table 1) during silking indicated that 5 larvae/plant (30%) were dominant. During the blister stage, however, 28.3% had 3 larvae/plant. In early dough, either 3, 4, or 5 larvae/plant were observed, ca. 26% at each level of infestation. In late dough, 61.7% of the plants had 5 larvae. During the dent stage, the infestation declined. Two larvae per plant were the most common during the late dent stage; more than 43% of the plants had no larvae.

Multiple infestations of plants by the corn earworm are presented in table 1. Two larvae/plant was the dominant infestation level during silking, blister and early dough stage. Percentages were 31.6, 22.5 and 22.5, respectively. However, during late dough and dent stage, most plants had only one larva. Infestations of 4 or 5 larvae/plant were recorded only during the blister stage (5%).

Both the fall armyworm and the corn earworm were observed feeding on the upper and lower ear (Table 2). The fall

armyworm at all stages of ear development was always the most abundant species, regardless of ear position.

The ratio of fall armyworm/corn earworm was also determined. Data in table 3 show that the fall armyworm was more abundant than the corn earworm in all stages of corn growth. The corn earworm was relatively abundant only during the blister stage when the ratio reached 1.6:1.0. From the dough through the dent stage, the fall armyworm greatly outnumbered the corn earworm.

Fall armyworm and corn earworm infestation levels in early and late planted corn in 1978 are presented in table 4. The fall armyworm attacked corn during the mid-whorl and early-whorl stages in early and late planted corn, respectively. In both, the infestation continued throughout the tassel stage; thereafter, the fall armyworm infestation declined. The corn earworm population was synchronized with the presence of fresh silks. Although the infestation was monitored throughout ear developmental stages, no further increase was observed after the ears had reached the blister stage (Table 4).

The highest fall armyworm infestation levels were 24.8 and 100% in early and late planted corn respectively. The highest corn earworm infestation was 36.3 and 91.2% in early and late corn, respectively. These results indicate that planting date greatly affected the infestation levels of both pests. In general, late planted corn sustained the highest fall armyworm and corn earworm infestation level.

Damage to Corn Plant

Four levels of plant damage were observed in early planted corn, 1977 (Table 5). Damage level zero accounted for 84%. Damage levels of 2, 1 and 3 accounted for 6.2, 5.2 and 4.6%, respectively. Plant damage level 4 was not observed.

Data from corn plants evaluated to assess tassel damage, presented in table 6, indicate that 88% of the observed plants had no tassel damage. Tassel damage ranging from 25-75% was observed on 6.2% of the plants. Plants with tassel broken above the distal quarter accounted for 3.8%. More than 75% of tassel was completely eaten away in 2% of the plants.

Damage derived from infestations during pretassel stages in late planted corn, 1977, is shown in table 7. Of the 551 plants rated, 315 presented no damage, 67 (12.2%) had slight damage, 73 (13.2%) moderate damage and 96 (17.5%) heavy damage. Severe plant damage was not observed.

Fall armyworm infestations during whorl stages resulted in tassel damage (Table 8). Of the 551 plants rated, 402 had no tassel damage; however, 149 showed levels of damage that ranged from almost total destruction to only slight feeding damage.

The fall armyworm was also observed feeding and boring into corn stalks (Figure 3). This behavior was first recorded during the blister stage, thereafter in all subsequent corn growth stages. The boring of stalks was recorded at two positions: above and below the upper ears. Comparatively few stalks were found bored below the ear and these only after the dough stage. At each stage of corn growth the number of bored stalks increased so that by the late dent stage, 78 and 22% of the plants showed boring activity above and below the ears, respectively. Those figures represent cumulative data from the blister to dent stage.

The fall armyworm and corn earworm shank damage resulted in dropped ears during late stages of ear development. The number of ears dislodged from the plant (Figure 4) after the blister stage increased rapidly.

Levels of damage in early planted corn in 1978 (Table 9) in decreasing order were: 0 (no visible damage), 4 (severe damage), 1 (slight damage), 2 (moderate damage) and 3 (heavy leaf damage). Slight damage, denoted by pinholes or shotholes, was commonly found on leaves 8 through 12 and leaf 16. Moderate damage was found on leaves 13-15. Heavy damage was observed on leaves 10-14. Complete leaf destruction was not localized on any specific plant region.

Late planted corn also showed five levels of damage (Table 9). The most frequent leaf damage was level three. This damage was localized on leaves 10 through 14. Damage

levels 1 and 2 were equal and also found on two different plant regions. Slight damage occurred on leaves 4-7 as well as on leaf 16. However, moderate damage was found on leaves 6-9 and 14-16. Severe leaf damage occurred only sporadically.

The number of leaves showing 0 damage decreased from the bottom to the top of the plant and was higher in early than in late planted corn. Leaf damage, in general, did not occur on the same plant regions for the two planting dates. In early planted corn the damage was localized on the upper portion of the plant whereas in late planted corn, the damage was not concentrated in any region. Only leaf damage level 3 was found on the same plant regions in both planting dates. Late planted corn sustained more fall armyworm leaf injury than early planted corn.

Discussion

Seasonal Abundance

The seasonal abundance data reported from this study indicate that both the fall armyworm and corn earworm show predominance at one time or another. The fall armyworm was the predominant species during the whorl stages. The population peak reached an infestation level of more than 10%. The corn earworm barely surpassed the 3% level during the same period. Previous investigations indicate that the corn earworm does not build up damaging populations in the spring

(Bishop, 1917). Extremely low fall armyworm and corn earworm population levels were recorded during tassel and early-blister stages of corn. At tasselling, corn leaves are completely unfolded and provide no protection for the larvae. This undoubtedly resulted in excessive larval mortality. High larval mortality has been reported as an important cause of population decline when plants are in the tassel stage (Morrill and Greene, 1973). During ear development the corn earworm was the dominant species. The presence of fresh silks is critical for corn earworm infestations (Dicke, 1939; Johnson, M. W. et al., 1975). However, in early planted corn, the ears developed at a time when fall armyworm and corn earworm density was low. Corn earworm population increased only after optimal silk conditions were past. Most larvae were observed to feed on the husk and senescent silks. McColloch (1924) reported that early planting reduces chances for corn earworm infestation.

High fall armyworm population levels were recorded during advanced stages of ear development as a result of a population that developed early during 1977. However the fall armyworm usually does not reach a high population level on developing ears (Morrill and Greene, 1973). The winter preceding the 1977 corn growing season was characterized by low temperatures and excessive precipitation (Table 34 and 35), climatic factors which appear ideal for fall armyworm outbreaks because they adversely affect natural enemies and favor growth of fall armyworm hosts (Luginbill, 1928).

The second corn earworm population peak in early planted corn occurred when populations of the fall armyworm were also increasing. Previous investigations indicate that both the corn earworm and fall armyworm are cannibalistic (Luginbill, 1928; Dicke, 1939) and cannibalism increases in relation to food shortage and mutual larval interference (Barber,1936). Relatively high fall armyworm numbers and subsequent cannibalism were probably responsible in part for the observed rapid corn earworm population decline. Similar conclusions have been reported previously (Ditman, 1950).

In late planted as in early planted corn, the two species appeared to be affected by the winter conditions that preceded the corn growing season (Table 34 and 35). During the late corn growing season, rainfall was well below the normal amount of previous years (Table 34 and 35). Sporadic precipitation and high relative humidity favored the fall armyworm (Walton and Luginbill, 1916) but adversely affected the corn earworm (Dicke, 1939; Ditman, 1943), primarily because dry conditions affect the quality of corn silks used as oviposition sites (McColloch, 1920). Population density levels were thus governed more by fall armyworm reproductive capacity and by inter- and intraspecific competition. Corn earworm populations were affected by environmental factors and by interspecific competition.

Both corn earworm and fall armyworm again infested ears and other plant parts during posttassel growth stages. The fall armyworm population which began in the mid-whorl stage

of early planted corn persisted throughout the entire growing season. The corn earworm which invaded early corn when silks were drying tended to build up a population in late corn in an already occupied niche by the fall armyworm. The two species coexisted for a brief period. However, both species exhibit cannibalistic behavior (Barber, 1936; Luginbill, 1928) which undoubtedly accounted for the abrupt decline in number of corn earworm. This phenomenon has been reported (Ditman, 1950).

In small plot evaluations of 1978, infestation patterns recorded from early and late planted corn (Table 4) show that fall armyworm larval number increased during pretassel stages; the corn earworm during ear developmental stages, regardless of planting date. The decline in fall armyworm infestation, consequently, coincided with the rise of corn earworm. Similar observations were recorded by Morrill and Greene (1973). Regardless of planting date, the infestation of the corn earworm coincided with the presence of fresh silk (Blanchard and Douglas, 1953).

Fall armyworm infestation levels and time of occurrence were also different. Fall armyworm infestations were initially detected during mid-whorl and early-whorl stages, in early and late planted corn, respectively. In late planted corn, the infestation levels were more than 3-fold the level recorded for early planted corn as was true for the 1977 field surveys. Likewise, corn earworm infestations were highest in late planted corn, a trend also observed in late planted corn in 1977.

In small plots as in field surveys, planting date affected fall armyworm and corn earworm infestation levels. Comparatively higher fall armyworm and corn earworm numbers were present in late than in early planted corn. Although effects of planting date on corn earworm have been reported (McColloch, 1924; Everly, 1961), relatively little is known about its influence on the fall armyworm (Mitchell, 1978). Generally, high corn earworm populations are expected in late planted corn (Dicke, 1939). Adults from overwintering stages probably initiated the infestation in early planted field corn where both species built up populations which caused heavy infestations in late planted corn.

Damage to Corn Plant

In 1977, plant damage was evaluated when corn reached the tassel stage. In both early and late planted corn, slight damage resulted from infestations that occurred prior to or at tasselling. Moderate damage originated from infestations sustained during the late-whorl stage. At this stage, the corn plant grows rapidly (Hanway, 1971). The unfolded leaves and emerging tassel exposed larval feeding sites and undoubtedly shortened the feeding period. Heavy damage resulted from comparable infestations during early- and mid-whorl stages when larvae were protected and had a prolonged feeding period.

The extended period of drought observed during this study caused the plants to be under moisture stress most of

the time. These conditions might result in prolonged larval feeding to compensate food quality for quantity and would, thus, result in more damage.

In early and late planted corn, tassel damage was always related to the time of infestation. Infestation occurring at or immediately prior to tassel emergence caused insignificant damage. However, considerable tassel destruction occurred from infestations during early-whorl stages.

Corn lodging due to weakened stalks was observed during advanced stages of ear development only in late planted corn. Fall armyworm but not corn earworm was found burrowing into the corn stalks. Larval penetration was complete and the larvae fed inside the stalks. Of the lodged plants, 78% were burrowed above the ears and 22% below the ears. Stalk attack weakened the plants which lodged in response to wind resulting in complete loss of ears. The incidence of stalk burrowing previously reported on corn (Wiseman et al., 1967b; Burkhardt, 1952) coincided with the population decline of the fall armyworm. The larvae moved from crowded and badly damaged or drying ears to seek a more safe and uncrowded niche to complete development.

All plants observed in late planted corn had at least one fall armyworm larva/plant. However, ear damage was not evaluated by any conventional method (Widstrom, 1967; Cox et al., 1964) because of the difficulties in finding an index to measure the diversity of injuries caused by the fall armyworm and corn earworm. A method was developed which

consisted of recording the number of ears dropped per meter-row. Dropped ears cannot be harvested and constitute a complete loss. Dropped ears were the result of fall armyworm feeding on ear shanks and from plant lodging.

Corn growth dynamics and infestation levels greatly influenced pest damage in 1978. Because of lower ambient temperature, early planted corn grows slower than late planted corn, which, however, is relatively less vigorous (Dr. E. Horner; personal communication). Fall armyworm infestation levels were also different, 24.8 and 100% in early and late planted corn, respectively (Table 4). Low infestation levels in connection with plant vigor were probably the factors that determined the amount of leaf damage in early planted corn. However, plant tissue differentiation was more rapid in late planted corn and the fall armyworm fed on tender tissue. The lesions caused by feeding may have enlarged as a result of accelerated growth. High fall armyworm infestation levels and accelerated growth might have contributed to the increase in fall armyworm feeding damage observed in late planted corn.

Early planted corn sustained most damage on the topmost leaves. In late planted corn, the damage was generalized and was not concentrated on any particular plant region. The fall armyworm infestation was highest during the late whorl stage in early planted corn (Table 4). Late corn supported largest fall armyworm infestation from early- through late-whorl stages. Infestation level and time as well as corn vertical growth rate probably accounted for this result.

Sometimes the same level of leaf injury appeared on two different plant regions. New exposed leaves were probably the target of subsequent fall armyworm infestations. The similar levels of leaf injury occurring on the different plant regions were probably the outcome of infestation taking place at different stages of corn growth on the same plants.

Loss of foliar area may result in yield reduction (Morrill, 1971). Bottom leaves contribute little to ear development; whereas removal of top leaves greatly reduces yield (Prine, 1962). In early planted corn, most slight damage was localized on bottom leaves. Both planting dates showed moderate and heavy damage on the topmost leaves. However, the percentages of damaged leaves were highest in late planted corn. Also the frequency and nature of leaf damage by the fall armyworm was highest in late planted corn where damage occurred on bottom, middle, and top leaves. Fall armyworm damage in early planted corn was probably not as great as in late corn. Therefore yield reduction from foliar loss is most likely to occur in late planted corn.

Conclusions

Mixed fall armyworm and corn earworm populations in early planted field corn, Coker 77, from mid-whorl stage through maturity, surpassed the 10% infestation levels and were responsible for moderate plant damage and without growth

loss. Tassel damage probably is not very important. Airborne pollen from neighboring plants is usually sufficient to fertilize ears on those plants that have lost their tassels.

An outbreak of the fall armyworm in late planted field corn, McNair 508, brought on by adverse climatic conditions during preplanting and during the corn growing season, rendered the host susceptible to excessive damage and fragile to windy conditions. Damage attributed to the fall armyworm included leaf damage, tassel damage, stalk breakage and ear destruction.

In 1978, the fall armyworm was the dominant species during pretassel stages; the corn earworm during ear developmental stages, regardless of planting dates.

Planting dates affected the infestation levels of both species. Highest fall armyworm and corn earworm infestations were recorded in late planted corn.

In early planted corn, most leaf damage was concentrated on the upper parts of the corn plant whereas, in late planted corn, the leaf damage was generalized and occurred on bottom, middle and top leaves. Frequency and damage intensity was higher in late than in early planted corn. Time of infestation and level as well as corn growth dynamics were important factors in the stratification and nature of leaf damage.

Table 1. Multiple infestation of corn plants by the fall armyworm, Spodoptera frugiperda (J. E. Smith), and Heliothis zea (Boddie) in late planted field corn, McNair 508, in Alachua Co. Florida, in 1977.

Infestation Larvae/ Plant	Species and Average Number of Plants at Growth Stage*											
	Fall armyworm						Corn earworm					
	Silking	Blister	Dough		Dent		Silking	Blister	Dough		Dent	
			Early	Late	Early	Late			Early	Late	Early	Late
0	0	0	0	0	0	10.4	11.0	0	13.2	19.8	23.4	24.0
1	3.8	5.0	1.8	0.4	5.2	4.2	2.4	3.8	4.0	2.4	0.6	0
2	3.2	5.6	3.8	1.2	3.6	7.6	5.4	5.4	6.0	1.0	0	0
3	5.8	6.8	6.2	2.8	5.4	1.8	3.2	4.2	0.8	0.8	0	0
4	3.6	3.8	6.2	5.0	3.8	0	0	2.0	0	0	0	0
5	7.2	3.6	6.2	14.8	4.0	0	0	1.2	0	0	0	0

* Average from 40 m-row.

Table 2. Average numbers of fall armyworm, Spodoptera frugiperda (J. E. Smith), and corn earworm, Heliothis zea (Boddie), infesting the upper and lower corn ears during different stages of development, in Alachua Co. Florida, 1977

Species	Ear Position	Average Number of Larvae Observed at Growth Stage					
		Silking	Blister	Dough		Dent	
				Early	Late	Early	Late
Fall armyworm	Upper	41.4	38.0	42.2	66.2	38.8	18.6
Corn earworm	Upper	4.8	20.6	9.0	3.8	0	0
Fall armyworm	Lower	30.0	24.6	34.6	38.8	27.4	4.8
Corn earworm	Lower	5.2	19.6	5.8	1.0	0	0

*Averages from 40 m-row.

Table 3. Ratio of fall armyworm, Spodoptera frugiperda (J. E. Smith), and corn earworm, Heliothis zea (Boddie), during different stages of ear development in late planted field corn, in Alachua Co. Florida, in 1977.

Species	Ratio at Growth Stage*					
	Silking	Blister	Dough		Dent	
			Early	Late	Early	Late
Fall armyworm	6.8	1.6	5.6	20.0	69.0	25.0
Corn earworm	1	1	1	1	0	0

* Averages from 40 m-row.

Table 4. Fall armyworm, Spodoptera frugiperda (J. E. Smith), and corn earworm, Heliothis zea (Boddie), infestation levels recorded during different growth stages of early and late planted field corn in Alachua Co. Florida, 1978.

Corn Growth Stage	Planting/Infestation Level			
	Early Planting		Late Planting	
	Fall armyworm	Corn earworm	Fall armyworm	Corn earworm
Early-whorl	0	0	4.7	0
Early-whorl	0	0	18.2	0
Mid-whorl	2.8	0	69.2	0
Mid-whorl	10.3	0	90.2	0
Late-whorl	20.0	0	98.0	0
Late-whorl	24.8	0	100.0	0
Tassel	23.8	0.3	3.6	9.2
Silking	11.3	4.8	4.0	42.2
Blister	5.0	30.0	0	88.0
Blister	5.3	36.3	0	91.2
Dough	0	36.3	0	91.2
Dough	0	36.3	0	91.2

Table 5. Levels of plant damage associated with Spodoptera frugiperda (J. E. Smith) and Heliothis zea (Boddie) feeding activities in early planted field corn, Coker 77, in Alachua Co. Florida in 1977.

Plants	Damage Levels[1/]					
	None 0	Slight 1	Moderate 2	Heavy 3	Severe 4	Total
Number	420	26	31	23	0	500
Percent	84	5.2	6.2	4.6	0	100

1/Ratings based on T. R. Ashley's scale:

0 - no visible damage.
1 - slight; pinholes, shot-holes, small lesions.
2 - moderate; less than 50% of the leaves with lesions or leaf sections eaten away.
3 - heavy; greater than 50% of the leaves with lesions or sections eaten away.
4 - severe; whorl destroyed to the point of retarding plant; no tassel formed.

Table 6. Levels of tassel damage associated with Spodoptera frugiperda (J. E. Smith) and Heliothis zea (Boddie) in early planted field corn, Coker 77, in Alachua Co. Florida, in 1977.

Plants	Damage Levels[1]				
	None 0	Less than 25% 1	50-75% 2	More than 75% 3	Total
Number	440	19	31	10	500
Percent	88	3.8	6.2	2.0	100

1/ Ratings:
0 - No visible damage.
1 - less than 25% eaten away.
2 - from 25-75% eaten away.
3 - more than 75% eaten away.

Table 7. Levels of plant damage associated with fall armyworm, Spodoptera frugiperda (J. E. Smith), infestations during pretassel stages of corn growth, in late planted field corn, McNair 508, in Alachua Co. Florida, in 1977.

Plant	Average No. of plants and damage rating1/					
	No damage 0	Slight 1	Moderate 2	Heavy 3	Severe 4	Total
Number	315	67	73	96	0	551
Percent	57.16	12.15	13.24	17.47	0	100

1/Ratings based on T. R. Ashley's scale:

0 - no visible damage.
1 - slight; pinholes, shot-holes, small lesions.
2 - moderate; less than 50% of the leaves with lesions or leaf sections eaten away.
3 - severe; whorl destroyed to the point of retarding plant; no tassel formed.

Table 8. Levels of tassel damage associated with fall armyworm, Spodoptera frugiperda (J. E. Smith), feeding in late planted corn, McNair 508, in Alachua Co. Florida, 1977.

Plants	Average Number of Plants at Each Tassel Damage*					
	No damage Level 0	Less than 25% Level 1	25-50% Level 2	50-75% Level 3	More than 75% Level 4	Total
Number	402	18	29	47	55	551
Percent	72.29	3.26	5.26	8.52	9.98	100

*Rating:
0 - no visible damage
1 - less than 25% eaten away.
2 - from 25-50% eaten away.
3 - from 50-75% eaten away.
4 - more than 75% eaten away.

Table 9. Leaf damage resulting from fall armyworm, Spodoptera frugiperda (J. E. Smith), feeding on early planted field corn: position according to the leaf number, level and percentage, Alachua Co. Florida, 1978.

Leaf Number	Early Planting		Late Planting	
	Damage Level	Percent	Damage Level	Percent
1	0	100	0	85
	1	0	1	15
	2	0	2	0
	3	0	3	0
	4	0	4	0
2	0	98	0	79
	1	2	1	21
	2	0	2	0
	3	0	3	0
	4	0	4	0
3	0	97	0	72
	1	3	1	28
	2	0	2	0
	3	0	3	0
	4	0	4	0
4	0	91	0	50
	1	8	1	45
	2	1	2	5
	3	0	3	0
	4	0	4	0
5	0	81	0	28
	1	17	1	57
	2	1	2	14
	3	1	3	1
	4	0	4	0
6	0	68	0	17
	1	28	1	49
	2	1	2	30
	3	3	3	30
	4	0	4	0

Table 9-continued

7	0	60	0	9
	1	30	1	53
	2	5	2	37
	3	4	3	10
	4	1	4	0
8	0	42	0	5
	1	41	1	26
	2	9	2	46
	3	7	3	23
	4	1	4	0
9	0	30	0	3
	1	44	1	16
	2	14	2	32
	3	11	3	49
	4	1	4	0
10	0	17	0	2
	1	50	1	7
	2	14	2	24
	3	19	3	66
	4	0	4	1
11	0	11	0	0
	1	51	1	6
	2	15	2	16
	3	22	3	78
	4	1	4	0
12	0	10	0	0
	1	40	1	4
	2	26	2	13
	3	23	3	83
	4	1	4	0
13	0	6	0	0
	1	34	1	7
	2	38	2	14
	3	22	3	79
	4	0	4	0
14	0	6	0	0
	1	27	1	7
	2	44	2	35
	3	23	3	58
	4	0	4	0

Table 9-continued

15	0	12	0	2
	1	34	1	22
	2	45	2	52
	3	9	3	24
	4	0	4	9
16	0	20	0	9
	1	67	1	56
	2	9	2	31
	3	3	3	3
	4	1	4	1

0 - no visible damage.
1 - slight; pinholes, shot-holes, small lesions.
2 - moderate; leaves with less than 50% eaten away.
3 - heavy; leaves with more than 50% eaten away.
4 - severe; leaf completely destroyed.

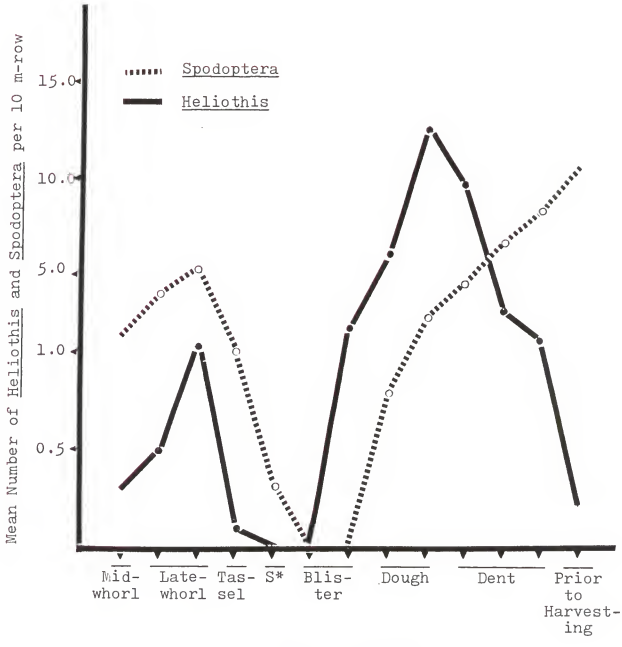

Figure 1. Seasonal abundance of Spodoptera frugiperda and Heliothis zea in early planted field corn, Coker 77, in Alachua Co. Florida, 1977.

*S=silking

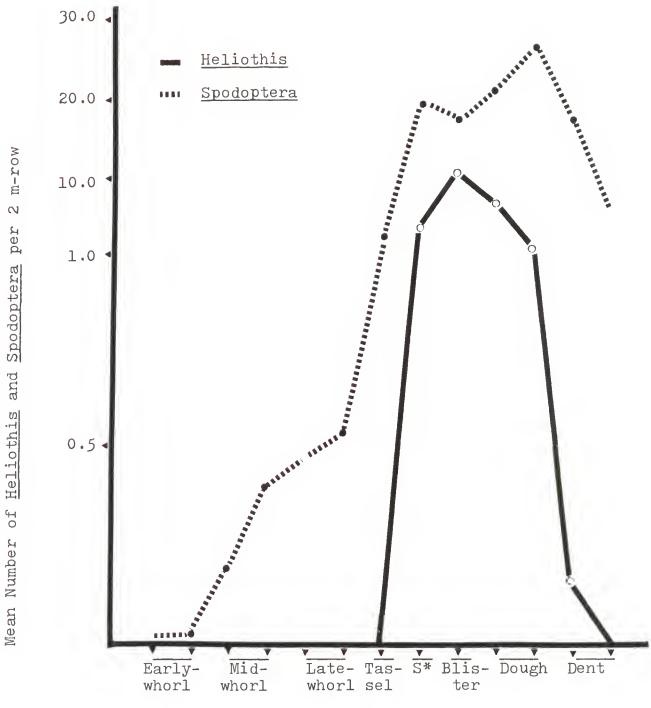

Figure 2. Seasonal abundance of Spodoptera frugiperda and Heliothis zea in late planted field field corn, McNair 508, in Alachua Co. Florida, 1977.

*S=silking

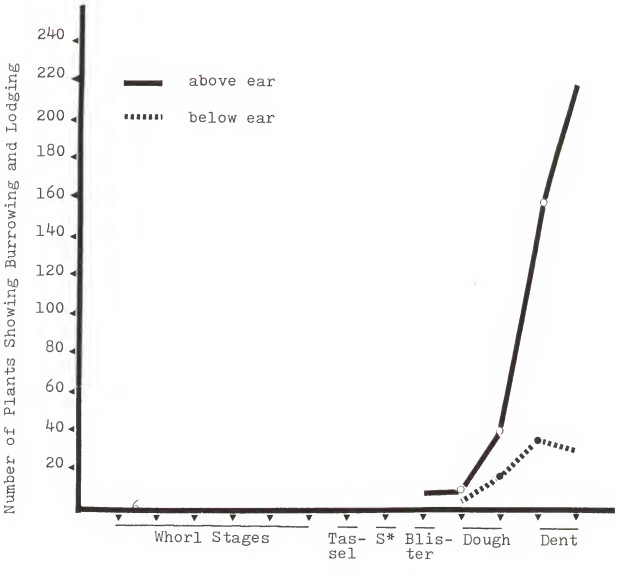

Figure 3. Corn stalk breakage at different stages of corn growth.

*S=silking

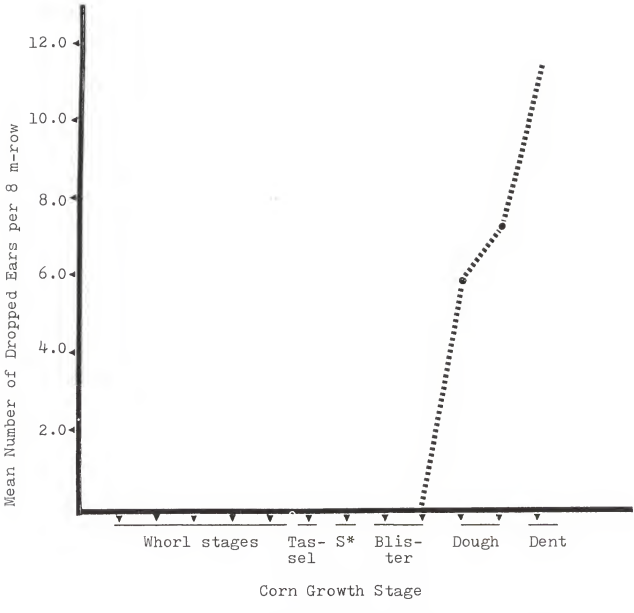

Figure 4. Shank damage as measured by the number of dropped ears during different stages of corn growth.

*S=silking

CHAPTER III

SOIL PESTS IN FIELD CORN: SEASONAL POPULATION ABUNDANCE AND THE EFFECT OF PEST MANAGEMENT STRATEGIES

Introduction

Soil pests of corn include both nematodes and insects (Dunn, 1978; Johnson, J. T. et al., 1974). Sixteen species representing 6 genera of nematodes have been recorded in surveys in corn-producing areas (Griffin, 1964; Graham and Holdeman, 1953). Pathogenicity tests indicate a cause-effect relationship for some of the species (Dickerson et al., 1964; Endo, 1967). Nematode infestations have been observed in field corn and other crops (Graham and Holdeman, 1953; Young, 1964; Rhoades, 1968) and nematicide treatments have usually decreased nematode populations and prevented yield losses (Dickson and Johnson, 1974; Norton et al., 1978).

Seasonal fluctuation of four species of nematodes in field corn was investigated by Brodie et al. (1969) who studied the dynamics of Pratylenchus zeae, Trichodorus cristiei, Helicotylenchus dihystera, and Xiphinema americanum. Similar research has been conducted on other nematode genera (Barker et al., 1969; Johnson, A. W. et al., 1974; Kimpinski et al., 1977).

Several soil insects are pests of corn. At least 50 species have been recorded as soil pests worldwide (Chiang, 1978). Six genera are found in Florida (Johnson, J. T. et al., 1974). These pests, a heterogeneous group of species from several orders and many families, are collectively known as the corn soil insect complex (National Academy of Science, 1975). The species complex of wireworms (Elateridae), cutworms (Noctuidae) and stalk borers (Pyralidae) is most likely to be found in Florida field corn (Johnson, J. T. et al., 1974).

Carbofuran, a multipurpose pesticide, has been used to control nematodes and soil insect pests in field corn (Johnson and Dickson, 1973; DuRant, 1975; Ghidiu et al., 1975; Johnson, A. W. et al., 1975). The use of nematicide-insecticide in situations where both insect and nematode infestations occur lowers the cost of control compared to using 2 single compounds (All and Jellum, 1977).

The study here reported was conducted to determine: a) the seasonal abundance of nematodes in early and late planted field corn and b) the effect of pest management strategies on soil insect pests and nematodes in early and late planted corn.

Materials and Methods

Experiment 1. Early-planted corn. The study areas were two 4.8 commercial fields of corn located about 5 km west of Gainesville. In field 1, the soil was partly characterized as fine sand sparr variant and the rest as lochloosa series (Standard Soil Survey Alachua Co. Florida, 1978). The corn hybrid was Coker 77, planted March 6, 1977, in both fields. The soils were treated with alachlor at a rate 3.3 kg ai/ha and carbofuran at 1.12 kg ai/ha. The entire fields were fertilized with 337 kg/ha of 10-10-30 and two subsequent side-dressings of anhydrous ammonia with 112.2 kg/ha. The sampling was conducted from March-July, 1977.

Five sites were selected in each corn field and sampled for nematodes at different stages of corn growth. The sample consisted of 10 soil cores taken to a depth of 15-20 cm and randomly collected from the root zone of different plants. The soil was thoroughly mixed and the nematodes were extracted from 100 cc soil by centrifugal-flotation (Jenkins, 1964). Root samples were also taken when corn was mature. At each site 5 plants were dug, the roots cut and prepared for assay. Nematodes were recovered from the roots by the modified Baermann funnel technique over a period of 24 hours (Powell

and Nusbaum, 1963). Climatological data during the study period were those recorded for Gainesville (Table 34 and 35).

Experiment 2. Late planted corn. The study area was a 7.69 ha commercial field of corn located 24 km west of Gainesville. The soil was a fine sand lochloosa series (Standard Soil Survey Alachua Co. Florida, 1978). The corn hybrid was McNair 508, planted April 10, 1977. The distance between plants was irregular, but on the average, there were 6 plants/2 m. The rows were 100 cm apart. The soil was treated with butylate + atrazine at a rate 3.36 + 2.24 kg ai/ha, respectively, and carbofuran at 1.12 kg ai/ha. The entire field was fertilized with 337 kg/ha of 10-10-30 and a subsequent sidedressing of ammonium nitrate with 112.2 kg/ha. The sampling was conducted from March-August, 1977.

Other than field size, the methods were as described in experiment 1.

Experiment 3. Early and late planted corn, 1978. The research was conducted at Green Acres, University of Florida Experimental Station during the spring and summer, 1978. The materials and methods apply to both early and late planted field corn. The soil was characterized as fine sand lochloosa series (Standard Soil Survey Alachua Co. Florida, 1978). The hybrid Coker 77 was planted April 5 and McNair 508 April 28, respectively. In both plantings, the distance between plants was 20 cm in rows 91 cm apart. Both fields were fertilized before

planting with 4-8-16 at 785.63 kg/ha and one sidedressing of ammonium nitrate at 112 kg/ha thirty days after planting.

A randomized block design was used for each planting date laid out over an area of 3416.64 m^2. Early planted field corn consisted of four treatments, each replicated four times. Each replicate was 8.80 x 12.12 m^2. Late planted corn had the same number of treatments but was replicated three times. Each replicate was 10.92 x 12.12 m^2.

The treatments, hereafter called strategies, were as follows:

Strategy A. To control weeds and the complex of Heliothis-Spodoptera with pesticides. No treatment was made for soil pests. Atrazine at 1.12 kg ai/ha was applied postemergence 10 days after planting and before the corn was 12.7 cm tall. Methomyl, 0.5 kg ai/ha, was applied as needed to control Heliothis-Spodoptera.

Strategy B. To control soil pests and Heliothis-Spodoptera but not weeds. The soil was treated with carbofuran at 2.24 kg ai/ha. Methomyl, at the above rate, was applied as needed.

Strategy C. To control weeds and soil pests but not Heliothis-Spodoptera. The pesticides, rates, and application time were those mentioned above.

Strategy D. To control weeds, soil pests, and Heliothis-Spodoptera with recommended pesticides. The rates, application time, and frequency were as described.

Upon corn emergence from the soil, the fields were surveyed daily to determine damage to corn plants by soil pests.

The methods were as described in experiment 1 except that 5 plants per replicate were dug and prepared for nematode extraction. The nematodes were recovered from 20 gm of roots. Root samples were taken when the corn was in the blister stage and prior to harvesting.

Results

Nematode populations were studied in early planted field corn, Coker 77. Six genera of parasitic nematodes were recovered from the samples; these were Meloidogyne spp., Pratylenchus spp., Helicotylenchus spp., Trichodorus spp., Criconemoides spp., and Xiphinema spp. (Table 10 and 11).

The soil samples assayed yielded a total of 4057 and 4788 nematodes for field 1 and 2, respectively. The most abundant genera were the ring nematode, Criconemoides spp., and the root-knot nematode, Meloidogyne spp. The other genera in decreasing order were Pratylenchus spp., Helicotylenchus spp., Trichodorus spp. and Xiphinema spp.

Root samples yielded a total of 2603 and 2348 nematodes for field 1 and 2, respectively. Two genera were recovered from root samples: Pratylenchus spp. and Meloidogyne spp. (Table 10 and 11). The root-knot nematode was more abundant than the lesion nematode in field 1. In field 2, the situation was reversed, and Pratylenchus was the dominant genus.

The population density of Criconemoides fluctuated similarly in both fields. Initially the population declined as corn advanced from the 3-leaf to mid-whorl stage. Thereafter, the population increased in relation to corn development and peaked when corn was in the dent stage (Table 10 and 11).

The population trend of Meloidogyne was found closely allied to corn phenology. The more advanced the stage of corn development, the higher the number of root-knot nematodes in field corn. The time and population peaks were different for the two fields. In field 1, the population peaked when corn was in the dent stage; but in field 2, during the blister stage (Table 10 and 11).

The population densities of Pratylenchus, Helicotylenchus, Trichodorus and Xiphinema were relatively low during the sampling period in both fields. The nematode counts were erratic from field to field and within fields. No particular population trend relative to corn phenology was observed for these nematodes.

In general, the results (Table 10 and 11) indicated that most nematodes, number and genera, were found from mid-whorl throughout the corn dent stage.

In the late planted corn, McNair 508, four genera of nematodes (3894 specimens) were recovered from the soil samples: the Meloidogyne spp., Pratylenchus spp., Criconemoides spp., and Xiphinema spp. (Table 12). Meloidogyne was most abundant, followed by Criconemoides and Xiphinema. From root samples, 1687 nematodes were recovered, primarily Meloidogyne and Pratylenchus.

Meloidogyne increased during plant growth, and the population peaked when corn was in the blister stage, and then declined as the corn matured. Criconemoides was recovered earlier than Meloidogyne. The older the corn plant, the more abundant the Criconemoides nematode (Table 14 and 15). Few Xiphinema were detected, and then only during the early-whorl stage.

Large numbers of nematodes are likely to be found from early-whorl to blister stage of corn growth. Root samples yielded most nematodes when the corn was fully mature.

In management strategies B, C, and D, a multipurpose pesticide, carbofuran, was used to control nematodes and soil pests in early and late planted corn, Coker 77 and McNair 508, respectively. Insect surveys did not indicate the presence of cutworms or corn stalk borers in either corn system nor did plants show characteristic damage of insect attack (Kulash, 1947; Kulash and Monroe, 1955).

Nematode sampling yielded information about two common nematodes of corn, the lesion nematode, Pratylenchus spp. and the root-knot nematode, Meloidogyne spp. (Table 13 and 14). Both corn systems, regardless of the strategy, were infested with nematodes, and Pratylenchus was the dominant genus. Early and late planted corn supported almost similar numbers of nematodes. Nematode populations were significantly different ($P=0.05$) in early planted field corn (Table 14). Pratylenchus was most abundant in untreated carbofuran plots. No significant differences were detected among plots receiving carbofuran,

atrazine, or both. Plots treated with both pesticides had relatively fewer nematodes than plots treated only with carbofuran. Meloidogyne populations were also significantly different (P=0.05) in early planted corn (Table 14). The untreated plots had the highest nematode numbers. Atrazine and carbofuran treated plots had fewer nematodes than plots receiving only one pesticide. Pratylenchus and Meloidogyne populations were not significantly different in late planted field corn (Table 14), and the strategies did not influence nematode density level. Except for Meloidogyne in early planted corn (P=0.09), the density population levels of both genera increased over the study period. Highest nematode numbers were recorded when corn was ready to be harvested (Table 13).

Discussion

Corn and other grass crops are hosts for several nematode species (Good, 1972; Roman, 1968), and high populations of nematodes on corn were not surprising. The population trends of Meloidogyne and Criconemoides were more or less similar to that shown by previous work (Johnson, A. W. et al., 1974). These authors reported that the Meloidogyne and Criconemoides populations peaked in late July. The chronological date corresponds to the phenological date observed in this study.

In early planted corn, Meloidogyne spp. was almost as abundant as the ring nematode in field 1 and 2. Large Meloidogyne populations were not observed during early growth stages of corn. The Meloidogyne population fluctuated widely. During the increasing trend, from one corn growth stage to another, the density levels increased to more than twice the previous level. Similar work has shown that the Meloidogyne population increased slowly during the corn growing season (Graham and Holdeman, 1951). The Meloidogyne population peak was almost simultaneous with that of Criconemoides. Similar results were reported by Johnson, A. W. et al. (1974). There were variations in Meloidogyne population peaks between field 1 and 2. Soil infestation levels probably accounted for this result since Meloidogyne was recovered earlier from field 2 than from field 1. In both fields, high population levels were recorded from mid-whorl throughout the corn dent stage.

In late planted corn, Pratylenchus spp. was not recovered from soil samples. Root samples taken from mature plants indicate that the lesion nematode was present in the corn system but at relatively low densities.

Trichodorus, Helicotylenchus and Xiphinema were found at relatively low densities in early planted corn, and Xiphinema in late planted corn. The low densities were not unexpected since these genera have low survival rates in monocultured corn (Brodie et al., 1969).

Two factors which may have overriding influence on the results herein reported are the use of agricultural chemicals and the extended period of drought observed during the sampling period (Table 34 and 35). Good (1968) reported that fertilizers, fumigants, herbicides, and soil moisture affected nematode populations. In this study, chemicals, with the exception of fumigants, were used at one time or another during the sampling period. The drought was the most lasting stress factor since rainfall was rather limited. During the study, 338.05 mm of rainfall were recorded. The expected rainfall, according to 70 year records, was 860.61 mm.

In pest management strategies B, C, and D, a multipurpose soil pesticide, carbofuran, was used to control nematodes and soil insect pests in early and late planted field corn, Coker 77 and McNair 508, respectively. The treatment was considered as a preventive application. Insect surveys did not reveal the presence of soil pests for either planting date. Previous research has determined that soil pests vary in number as well as in species composition from year to year (Baranowski and Waddill, 1975). Similar effects are caused by crop rotation and continuous cropping (Bigger and Blanchard, 1955). Soil pest destructiveness also varies spatially and temporally (National Academy of Science, 1975). The absence of soil insect pests in untreated plots may be the result of either an unfavorable year for soil pests or

the intensive agricultural use of the experimental area on which this study was done.

Large populations of nematodes were recovered from root samples taken in early and late planted corn, regardless of the strategy. Typical symptoms of nematode attack were not observed on the corn plant (Dunn, 1978). The strategies did not greatly influence the nematode populations. The mode of action of carbofuran on nematodes is not well understood (Daynard et al., 1975). Di Sanzo (1973) suggested that carbofuran affects the orientation and feeding mechanism of nematodes and it is possible to find nematodes in carbofuran treated plots. Comparatively fewer nematodes were recovered from plants grown in combined atrazine + carbofuran treated plots than from plants in carbofuran or atrazine treated plots. Johnson, A. W. et al. (1975) also reported this phenomenon. Higher numbers of nematodes were found prior to harvesting than during the blister stage. The nematode population increased more than 4-fold above the levels recorded during the blister stage. Pratylenchus numbers increased in all strategies and planting dates. Meloidogyne increased only in late planted corn. Previous research has shown that nematode population increases throughout the corn growing season despite nematicide treatments (Johnson and Chalfant, 1973; Kimpinski et al., 1977). The nematode population in both corn systems is attributed to the fact that corn is a good host for several nematode genera (Roman, 1968). Soil treatments were probably effective during early stages

of corn growth (Johnson and Dickson, 1973), and the corn seedlings were probably free of nematodes. None of the strategies interfered with the subsequent build up of nematodes on corn, however.

Conclusions

In early planted field corn, Coker 77, six genera of nematodes were recovered from root and soil samples: Meloidogyne spp., Pratylenchus spp., Trichodorus spp., Helicotylenchus spp., Criconemoides spp., and Xiphinema spp.

In late planted corn, McNair 508, only four genera of nematodes were recovered from the samples: Meloidogyne spp., Criconemoides spp., Xiphinema spp., and Pratylenchus spp.

Independently of sampling technique and planting date, Meloidogyne and Criconemoides were the most abundant nematodes in the corn systems. Most nematodes, number and genera, were found from mid-whorl throughout the dent stage of corn growth. Moisture stress probably affected the recovery of nematodes in this study.

In field corn grown under different soil treatment strategies, no soil pests were encountered in either early or late planted corn. Nematodes were recovered from plants in all the strategies and in both planting dates. Pratylenchus was the dominant genus in both early and late planted corn. Nematode populations increased as corn progressed

toward maturity. The planting date probably did not affect nematode populations. The soil treatment strategies (carbofuran and atrazine), under the conditions of this study, provided protection against nematodes only during early stages of corn growth.

Table 10. Nematode genera associated with early planted field corn, Coker 77, in Alachua Co. Florida, 1977 (Field 1)

Growth Stage	Sampling Method	Total and Average Number/Sample in Genus											
		Meloidogyne		Pratylenchus		Helicotylenchus		Trichodorus		Criconemoides		Xiphinema	
		Total	Average	Total	Average	Total	Average	Total	Average	Total	Average	Total	Average
3-leaf	core	0	0.0	3	0.6	6	1.2	0	0.0	411	82.2	3	0.6
Mid-whorl	core	0	0.0	6	1.2	24	4.0	0	0.0	146	29.2	0	0.0
Late-whorl	core	35	7.0	0	0.0	24	4.8	3	0.6	37	7.4	3	0.6
Blister	core	89	17.8	0	0.0	0	0.0	0	0.0	234	46.8	0	0.0
Dent	core	481	96.2	370	74.0	87	17.4	23	46.0	1416	283.2	0	0.0
Maturity	core	416	83.2	0	0.0	0	0.0	3	0.6	234	46.8	3	0.6
Maturity	root	1008	217.6	1515	303.0	0	0.0	0	0.0	0	0.0	0	0.0
Total		2109		1894		141		29		2478		9	

Core = 100 cc soil
Root = 10 gm

Table 11. Nematode populations associated with early planted field corn, Coker 77, in Alachua Co. Florida, 1977 (Field 2)

Growth Stage	Sampling Method	Total and Average Number/Sample in Genus											
		Meloidogyne		Pratylenchus		Helicotylenchus		Trichodorus		Criconemoides		Xiphinema	
		Total	Average	Total	Average	Total	Average	Total	Average	Total	Average	Total	Average
3-leaf	core	0	0.0	0	0.0	0	0.0	13	2.6	370	74.0	0	0.0
Mid-whorl	core	10	2.0	13	2.6	0	0.0	31	6.2	57	11.4	10	2.0
Late-whorl	core	153	30.6	0	0.0	0	0.0	16	3.2	108	21.6	0	0.0
Blister	core	720	144.0	3	0.6	0	0.0	3	0.6	240	48.0	0	0.0
Dent	core	422	84.4	7	1.4	76	15.2	7	1.4	852	170.4	3	0.6
Maturity	core	537	107.4	86	17.2	0	0.0	9	1.8	1001	200.2	41	8.2
Maturity	root	415	83.0	1969	393.8	0	0.0	0	0.0	0	0.0	0	0.0

Core = 100 cc soil
Root = 10 gm

Table 12. Nematode genera associated with late planted field corn, McNair 508, in Alachua Co. Florida, 1977.

Growth Stage	Sampling Method	Total and Average Number/Sample in Genus							
		Meloidogyne		Pratylenchus		Ciconemoides		Xiphinema	
		Total	Average	Total	Average	Total	Average	Total	Average
Early-whorl	Core	0	0	0	0	30	6	61	12.2
Blister	Core	852	170.4	0	0	269	53.8	0	0
Maturity	Core	195	39	0	0	295	59	0	0
Maturity	Root	1614	322.8	73	14.6	0	0	0	0
TOTAL		2661		73		594		61	

Core = 100 cc soil
Root = 10 gm

Table 13. Mean number of nematodes/20 gm of roots found in early and late planted field corn grown under different pest management strategies in Alachua Co. Florida, 1978.

Strategy	Mean Number of Nematodes at Growth Stage			
	Pratylenchus		Meloidogyne	
	Blister	Harvest	Blister	Harvest
Early Planting				
A	148.3	931.8	191.3	2.5
B	133.3	488.0	304.3	28.8
C	90.3	424.0	114.8	24.5
D	90.5	398.8	87.5	0
Late Planting				
A	156.0	708.7	0	80.2
B	23.0	376.7	1.0	143.2
C	75.7	1144.0	10.2	28.0
D	17.0	1005.0	4.7	25.2

A = Atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.
B = Carbofuran 2.24 kg ai/ha + methomyl 0.5 kg ai/ha.
C = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha.
D = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.

Table 14. Effect of different pest management strategies on nematode populations found in early and late planted field corn in Alachua Co. Florida, 1978.

Strategy	Mean Number of Nematodes per 20 gm Roots			
	Early Planting		Late Planting	
	Pratylenchus	Meloidogyne	Pratylenchus	Meloidogyne
A	540.0a	96.9b	432.2a	40.2a
B	310.5b	166.8a	199.7a	72.2a
C	257.0b	69.6b	609.7b	19.2a
D	244.5b	43.8bc	511.0a	15.0a

Means in each column followed by the same letter are not significantly different.

A = Atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.
B = Carbofuran 2.24 kg ai/ha + methomyl 0.5 kg ai/ha.
C = Carbofuran 2.24 kg ai/ha + methomyl 0.5 kg ai/ha.
D = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.

CHAPTER IV

GROUND ARTHROPODS IN FIELD CORN AND THEIR POPULATION RESPONSE TO PEST MANAGEMENT STRATEGIES

Introduction

Information on the occurrence, habitats, and seasonal distribution of ground arthropods found in agricultural lands is presented by Rivard (1964) and Kirk (1971). Ground beetles (Carabidae) are common components in different agrosystems (Esau and Peters, 1975; Sekulic, 1976) and under a wide range of pest management schemes (Price, 1977; Holliday and Hagley, 1978). Similarly, spiders (Yeargan and Cothran, 1974) and the striped earwig, Labidura riparia (Pallas) (Clements, 1968; Walker and Newman, 1976; Price, 1977; Travis, 1977) are common components.

The potential role of ground beetles (Best and Beegle, 1977) and striped earwig (Travis, 1977) as predators of agricultural pests has been investigated. Other studies have evaluated the biological potential of ground beetles as weed seed feeders (Lund and Turpin, 1977).

The abundance of ground fauna may be affected by environmental factors (Thiele, 1977) as well as by agrichemicals used for crop protection (Critchley, 1972; Price, 1977; Travis, 1977; Stam et al., 1978).

No reports are available concerning ground arthropods in North Florida corn fields. Information on the species' numerical and functional response would be useful in planning crop protection strategies which integrate control tactics and complement natural mortality with induced mortality.

The study here reported was conducted to determine: a) the seasonal abundance of ground arthropods in early and late planted corn and b) the effects of different pest management strategies on their abundance.

Materials and Methods

Experiment 1. The study area was a commercial field of corn about 5 km west of Gainesville. The soil was characterized as partially fine sand sparr variant and lochloosa series (Standard Soil Survey Alachua Co. Florida, 1978). The corn was hybrid Coker 77, planted March 6, 1977. The distance between plants was 20 cm in rows 100 cm apart. The soil was treated with carbofuran at a rate 1.12 kg ai/ha and alachlor at 3.3 kg ai/ha. The entire field was fertilized at 337 kg/ha with 10-10-30 and two subsequent sidedressings of anhydrous ammonia at 112.2 kg/ha, each.

Five sampling sites were located in the corn field. At each site, a pitfall trap was buried in the row with the rim level with the ground surface and half the distance between

two adjacent plants. Each trap consisted of a 500 cc plastic container supplied with a killing-preserving agent, ethylene glycol. Pitfall traps were protected from the rain by a wood cover 18 x 18 cm supported by four 8 cm legs driven into the ground 4 cm deep. The traps were serviced, preservative added, and catches tabulated weekly. The sampling period extended from March 23-June 1, 1977, during the active growing period of corn.

Growth stages of the corn were observed and recorded on each sampling date. The stages were established by comparing actual plant growth with those illustrated in a corn growth stage key (Hanway, 1971).

The ground species were ranked in order of abundance according to Rivard's (1964) scale, as follows: "Very rare, 10 specimens or less; Rare, 11 to 50; Common, 51 to 200; Abundant, over 200."

Climatological data during the study period were those recorded for Gainesville (Table 34 and 35).

Experiment 2. Research was conducted at Green Acres, University of Florida Experimental Station during the spring and summer, 1978. The materials and methods apply to both early and late planted field corn. The soil was characterized as fine sand lochloosa series (Standard Soil Survey Alachua Co. Florida, 1978). The hybrid, Coker 77, was planted April 5 and McNair 508 April 28. In both plantings, the distance between plants was 20 cm in rows 91 cm apart. Both fields

were fertilized before planting with 4-8-16 at 785.63 kg/ha and one sidedressing of ammonium nitrate at 112 kg/ha thirty days after planting.

A randomized block design was used for each planting date laid out over an area of 3416.64 m^2. Early planted field corn consisted of four treatments, each replicated four times. Each replicate was 8.80 x 12.12 m^2. Late planted corn had the same number of treatments but replicated three times. Each replicate was 10.92 x 12.12 m^2.

The treatments, hereafter called strategies, were as follows:

Strategy A. To control weeds and the complex of Heliothis-Spodoptera with pesticides. No treatment was made for soil pests. Atrazine at 1.12 kg ai/ha was applied postemergence 10 days after planting and before the corn was 12.7 cm tall. Methomyl, 0.50 kg ai/ha, was applied as needed to control Heliothis-Spodoptera.

Strategy B. To control soil pests and Heliothis-Spodoptera but not weeds. The soil was treated with carbofuran at 2.24 kg ai/ha. Methomyl, at the above rate, was applied as needed.

Strategy C. To control weeds and soil pests but not Heliothis-Spodoptera. The pesticides, rates, and application time were those mentioned above.

Strategy D. To control weeds, soil pests and Heliothis-Spodoptera with recommended pesticides. The rates, application time, and frequency were as described.

The methods were as described in experiment 1 except that the sampling dates were from March 14-July 28 and April 28-August 11 for early and late planted corn, respectively.

Results

For each corn growth stage, the families of ground arthropods trapped in pitfalls from early planted field corn, Coker 77, are listed in Table 15. The 546 specimens taken in this study belonged to 5 families and 10 genera.

Among the trapped fauna, 163 specimens were species reported to attack corn (Table 16). They were Conoderus scissus (Schffr.), Conoderus amplicollis (Gyll.) (Elateridae), Anisodactylus merula Germar (Carabidae) and Euphoria sepulchralis (Fab.) (Scarabeidae). E. sepulchralis was the most numerous of the potentially harmful species, and highest numbers were recorded at the end of early-whorl stage of corn (Table 15). Although C. amplicollis was in low numbers, it was collected during 8 consecutive weeks.

Three hundred eighty-three specimens were beneficial arthropods. Pardosa milvina (Hentz) (Lycosidae) was the most commonly collected species. Highest numbers of P. milvina, as reflected by the pitfall traps, occurred between the late-whorl and tassel stage of corn. Pasimachus sublaevis Beauv. (Carabidae) and Labidura riparia (Pallas)

(Labiduridae) were most numerous during the late-whorl stage. The catches of other species were erratic throughout the sampling period.

The species composition and numbers varied throughout the study period. Early in the season, harmful species were caught more frequently than beneficial arthropods. About equal numbers of harmful and beneficial species were collected during the mid-whorl stage. Thereafter, the beneficial species became the most numerous in the corn system (Table 16). The highest numbers and species diversity were recorded at the end of the late whorl stage.

In general, most of the carabid fauna fell in the categories rare or very rare. The exception was P. sublaevis which according to the data was considered a common species. Other common arthropods were E. sepulchralis and L. riparia (Table 17).

Pitfall traps were used to monitor the seasonal abundance of ground arthropods in early and late planted corn in 1978. The 56273 specimens collected in this study represented 5 families and 16 genera (Table 18-23), both beneficial as well as injurious. Among the pests, numbers of Anisodactylus merula Germar (Carabidae) were inconsistent during the sampling period (Table 21-26). Conoderus scissus (Schffr.) (Elateridae) was active only during early stages of corn growth. Conoderus amplicollis (Gyll.) (Elateridae) was caught during most of the corn growing season. Both species of Conoderus were more abundant in late than early

planted corn (Table 19 and 22). The management strategies did not have a significant influence on the numbers of pest species trapped.

The species were ranked in order of abundance according to Rivard's (1964) scale. The data (Table 24 and 25) indicate that the carabid and cicindelid fauna were either rare or very rare, regardless of planting date. The exception was Selenophorus palliatus Fabricius, which was very abundant from mid-season through corn maturity in late planted field corn (Table 22). The numbers of carabid species collected were inconsistent during the study period. They appeared to become most active from mid-whorl through dent stage of corn growth.

Regardless of planting date, Labidura riparia (Pallas) (Labiduridae) was the most abundant species. Its numbers were consistent throughout the corn growing season, but more were taken in late than in early planted corn (Table 20 and 23). Pardosa milvina (Hentz) (Lycosidae) showed the opposite trend. In general, the levels of the species activity fluctuated over the study period.

The strategies used to control corn pests did not seem to affect the activity of the ground fauna. Statistical analyses showed no significant differences among abundant species such as L. riparia, S. palliatus, and P. milvina. Abundant species were trapped indiscriminately in all plots.

No positive relationship between Labidura and the pest complex Heliothis-Spodoptera was discovered to indicate that

Labidura suppressed the population build up of these pests (Table 26 and 27). However, catches of Labidura appeared to be influenced by rainfall (Table 28).

Discussion

The seasonal abundance of ground arthropods was studied in early planted field corn, in 1977. No weeds were present in the corn system and all the vegetation surrounding the traps was corn. Therefore, all species were assumed to have an equal probability of being caught (Holliday and Hagley, 1978). The numbers and complex of species caught were inconsistent due to low precipitation. Only 338.05 mm of rainfall were recorded during the entire sampling period compared to the average of 860.51 mm recorded during 70 years for the same period. Soil and ambient humidity are known to affect carabids (Kirk, 1971). In addition, most ground arthropods are thigmotactic (Thiele, 1977). In dry soils, carabids as well as lycosids seek protection by hiding in deep soil cracks, where a more humid habitat is available. This habit makes difficult the acquisition of accurate samples (Kirk, 1971; Yeargan and Cothran, 1974). The catches both in numbers and species diversity were undoubtedly lower due to the drought.

Although carabids as a group cause natural mortality of agricultural pests, it is doubtful if a single species in

low numbers would be significant for pest control. Well-known predators such as Calosoma (Price, 1977) were not routinely caught in the corn system. Labidura was also not very numerous compared to previous studies, which indicate that this insect is very abundant in corn systems (Walker and Newman, 1976).

Despite the adverse environmental conditions, 10 genera of ground arthropods were recorded from early planted field corn. The species became most numerous during the late-whorl stage of corn. This period coincided with the incidence of corn pests that attack foliage but positive effect was not evident.

Rainfall during the research period of 1978 was variable. April and June were relatively dry; March, May, July, and August were normal to abnormally rainy months (Table 36). Small amounts of rainfall were recorded weekly during April and June. Therefore, soil moisture was probably not a limiting factor that influenced the carabid fauna. Trap catches increased when corn was in the mid-whorl stage of growth and after the sidedressing of ammonium nitrate carried out 30 days after planting. Carabids are known to concentrate in areas that receive nitrogen fertilizer and water (Lavigne and Campion, 1978). The activity of Labidura seemed to respond to corn growth and development. The older the corn plant, the more numerous the Labidura in the corn system. Clements (1968) also concluded that Labidura catches fluctuate according to rainfall. This was observed in this study (Table 28).

Pesticides are known to influence the population of ground arthropods (Critchley, 1972). In strategies A, C, and D, the application of atrazine could have affected the fround fauna in two ways: direct mortality (Stam et al., 1978) or by modifying the structural elements and vegetation surrounding the trap (Thiele, 1977). In early planted field corn, weeds never developed and all plots including those where atrazine was not applied were weed-free. Untreated plots, strategy B, in late planted field corn favored weed growth. Richardia scabra (L.), Cassia obtusifolia L., Eleucine indica Gaertn., Dactyloctenium aegyptium (L.) and Amaranthus sp. were found on these plots. The weeds did not seem to affect the activity of the ground fauna. The catches were not affected by the trap environment. Abundant species were collected indiscriminately regardless of the strategy. About equal numbers of the relatively inactive species were found in all strategies. Labidura and A. merula were trapped both prior to and after the herbicide treatment. Either the insects were not in contact with the chemical or were not susceptible to atrazine. Different species of arthropods vary in susceptibility to herbicide applications (Stam et al., 1978). Most of the carabids were not active at the time the herbicide was applied. Soil pests, such as Conoderus, were first collected 8 days after treatment.

Carbofuran did not appear to affect the activity of Labidura and A. merula. Both species were recorded 8 days

after treatment in late planted corn. Gholson et al. (1978) reported that the mortality of carabids in carbofuran treated plots was not significantly different from that recorded in untreated plots.

Methomyl, used to control Heliothis zea and Spodoptera frugiperda, had no detectable effect on the activity of ground arthropods. Statistical analyses for the collections of the most abundant species revealed no significant differences between strategies and arthropod activity. Labidura was present in all plots and the carabid catches were unaffected. In previous studies, it was concluded that insecticide formulation, chemical nature of the insecticide, application technique and season of the year can all modify the killing of terrestial arthropods by pesticides (Basedow et al., 1976).

Labidura is known to attack agricultural pests (Price, 1977; Travis, 1977). The activity of Labidura in corn of both planting dates, regardless of the strategy, as determined by the number of collected specimens, was high. Labidura was recorded before the appearance of Heliothis and Spodoptera, and increased throughout the season with highest numbers recorded when corn was mature and pests absent. Population levels of Heliothis and Spodoptera in methomyl untreated plots, strategy C, followed the population trend previously observed by Morrill and Greene (1973). In treated plots, the insecticide lowered the infestation levels. There is no evidence that Labidura affected the

population build up of Heliothis or Spodoptera in untreated plots. Labidura either does not climb high on the corn plant or other food was accessible on the ground. Previous investigations suggest that Labidura could be a regulating agent that checks wireworm populations in the field (Shepard et al., 1973) and also attacks Lycosa perita (Caussanel, 1970).

Conclusions

Ten genera of harmful and beneficial ground arthropods were collected by pitfall traps from early planted field corn, Coker 77, in 1977. The greatest numbers and species diversity were recorded during the late-whorl stage of corn growth. The carabid fauna, according to Rivard's scale, was rare or very rare. Labidura also was not very numerous. Well-known soil insect pests, such as Conoderus sp., were rare. The catch of species was probably affected by lack of rainfall during the growing season of 1977.

Sixteen genera of ground arthropods were recorded during 1978. As in 1977, the carabid fauna was not very numerous in early and late planted corn, with the exception of Selenophorus palliatus in the latter. Conoderus spp. were recorded during most of the season and were more active in late than early planted corn. Labidura was the most

abundant terrestial arthropod in both corn systems, regardless of the strategy and was influenced by planting dates. Labidura was more abundant in late planted field corn. Management strategies did not affect the ground fauna and Labidura had no measurable effect on Heliothis or Spodoptera.

Table 15. Abundance of arthropods collected by pitfall traps throughout growth stages of early planted field corn in Alachua Co., Florida, 1977.

Corn Growth Stage	Family and Number of Adult Specimens				
	Carabidae	Elateridae	Labiduridae	Lycosidae	Scarabeidae
3-leaf	1	0	0	1	7
Early-whorl	1	0	0	2	20
Early-whorl	1	2	4	5	50
Mid-whorl	3	2	5	7	17
Mid-whorl	8	2	7	8	10
Late-whorl	45	11	8	9	3
Late-whorl	16	4	23	53	0
Tassel	18	1	2	44	0
Blister	21	1	0	37	0
Blister	16	3	0	28	0
Dough	18	3	2	15	0

Table 16. Beneficial and harmful ground arthropods collected by pitfall traps at different stages of corn growth, in Alachua Co., Florida, 1977.

Corn Growth Stage	Number of Specimens Caught in Pitfall Traps	
	Beneficial	Harmful
3-leaf	1	8
Early-whorl	2	21
Early-whorl	9	53
Mid-whorl	13	21
Mid-whorl	45	32
Late-whorl	92	4
Tassel	64	1
Blister	58	1
Blister	43	4
Dough	35	3

Table 17. Relative abundance of ground arthropods in early planted field corn, Coker 77, in Alachua Co., Florida, 1977.

Family/Species	Number of Specimens	% of Total	Index
Carabidae			
Anisodactylus merula Germar	29	5.31	R
Calosoma externum Say	1	0.18	VR
Calosoma sayi Dejean	1	0.18	VR
Galerita janus (Fabricius)	5	0.91	VR
Galerita lecontei DeGeer	5	0.91	VR
Harpalus pennsylvanicus DeGeer	23	4.31	R
Pasimachus sublaevis Beauv.	72	13.18	C
Pasimachus subsulcatus Say	13	2.38	R
Elateridae			
Conoderus amplicollis (Gyll.)	19	3.47	R
Conoderus scissus (Schffr.)	11	2.01	R
Labiduridae			
Labidura riparia (Pallas)	51	9.34	C
Lycosidae			
Lycosa sp.	2	0.36	VR
Pardosa milvina (Hentz)	207	37.91	A
Scarabeidae			
Euphoria sepulchralis (Fab.)	107	19.59	C
TOTAL	546	100.00	

VR = very rare, 10 specimens or less; R = rare, 11-50; C = common, 51-200; A = abundant, over 200.

Table 18. Ground arthropods from pitfall traps in early planted field corn grown under different management strategies in Alachua Co., Florida, 1978.

Corn Growth Stage	Total Number of Specimens/Strategy											
	Carabidae				Cicindelidae				Lycosidae (*Lycosa* sp.)			
	A	B	C	D	A	B	C	D	A	B	C	D
3-leaf	0	1	0	0	0	0	0	0	0	0	0	0
Early-whorl	0	1	1	0	0	0	0	0	0	0	0	0
Early-whorl	0	1	0	0	0	0	0	0	0	0	0	0
Mid-whorl	0	0	1	0	0	0	0	0	0	0	0	0
Mid-whorl	2	2	0	1	0	0	0	0	2	0	1	0
Late-whorl	0	1	0	0	0	0	0	0	1	0	0	1
Late-whorl	2	3	2	2	0	0	0	0	0	0	0	0
Tassel	5	3	4	3	0	0	0	1	0	0	0	1
Silking	1	2	4	4	0	0	0	0	0	0	0	0
Blister	7	7	6	16	1	0	0	3	0	0	0	0
Blister	3	4	11	5	1	1	0	0	0	0	0	2
Dough	6	5	5	2	5	2	1	3	1	2	5	1
Dough	2	1	1	0	2	1	2	0	2	0	0	0
Dent	1	1	2	0	0	1	1	0	0	0	0	0
Dent	1	1	1	1	1	0	1	0	0	0	0	0

A = Atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.
B = Carbofuran 2.24 kg ai/ha + methomyl 0.5 kg ai/ha.
C = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha.
D = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.

Table 19. Ground arthropods, Conoderus scissus (Schffr.) and Conoderus amplicollis (Gyll.) (Elateridae), from pitfall traps in early planted field corn grown under different management strategies in Alachua Co., Florida, 1978.

Corn Growth Stage	Total Number of Specimens/Strategy							
	C. scissus*				C. amplicollis*			
	A	B	C	D	A	B	C	D
3-leaf	0	0	0	0	0	0	0	0
Early-whorl	0	0	0	0	0	0	0	0
Early-whorl	9	16	8	18	0	0	0	0
Mid-whorl	7	5	4	11	0	0	0	0
Mid-whorl	0	0	0	0	0	12	2	0
Late-whorl	0	0	0	0	35	12	5	2
Late-whorl	0	0	0	0	10	14	5	2
Tassel	0	0	0	0	12	40	35	21
Silking	0	0	0	0	6	4	5	5
Blister	0	0	0	0	0	2	6	3
Blister	0	0	0	0	22	15	12	18
Dough	0	0	0	0	6	3	5	1
Dough	0	0	0	0	33	49	47	47
Dent	0	0	0	0	23	19	25	41
Dent	0	0	0	0	29	32	25	22

* The collections were not significantly different at the 5% level.

A = Atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.
B = Carbofuran 2.24 kg ai/ha + methomyl 0.5 kg ai/ha.
C = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha.
D = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.

Table 20. Ground arthropods, Pardosa milvina (Hentz) (Lycosidae), and Labidura riparia (Pallas) (Labiduridae), from pitfall traps in early planted field corn grown under different management strategies, in Alachua Co., Florida, 1978.

Corn Growth Stage	Total Number of Specimens/Strategy							
	P. milvina*				L. riparia*			
	A	B	C	D	A	B	C	D
3-leaf	0	0	0	0	6	8	10	3
Early-whorl	0	0	0	0	6	5	3	0
Early-whorl	0	0	0	0	8	9	11	9
Mid-whorl	0	0	0	4	17	30	39	24
Mid-whorl	5	6	8	6	19	71	34	48
Late-whorl	3	3	1	2	91	218	121	119
Late-whorl	4	0	4	2	120	221	121	144
Tassel	23	16	24	16	101	140	187	113
Silking	46	66	36	50	201	252	205	285
Blister	30	34	21	34	121	96	135	116
Blister	28	39	43	43	368	272	487	268
Dough	61	46	63	58	489	222	497	305
Dough	35	36	40	44	848	680	849	803
Dent	42	38	47	44	540	515	458	618
Dent	7	24	13	13	1020	982	892	1025

*The collections were not significantly different at the 5% level.

A = Atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.
B = Carbofuran 2.24 kg ai/ha + methomyl 0.5 kg ai/ha.
C = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha.
D = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.

Table 21. Ground arthropods from pitfall traps in late planted field corn grown under different management strategies in Alachua Co., Florida, 1978.

Corn Growth Stage	Total Number of Specimens/Strategy											
	Carabidae				Cicindelidae				Lycosidae (*Lycosa* sp.)			
	A	B	C	D	A	B	C	D	A	B	C	D
3-leaf	0	4	1	0	0	0	0	0	0	0	0	0
Early-whorl	0	0	3	0	0	0	0	0	0	0	0	0
Early-whorl	0	1	0	0	0	0	0	0	0	0	0	0
Mid-whorl	0	0	1	0	0	0	0	0	0	0	0	0
Mid-whorl	2	9	8	3	0	0	0	0	0	0	0	0
Late-whorl	1	3	5	5	1	0	0	1	0	0	0	0
Late-whorl	5	10	4	10	0	0	0	0	0	0	0	0
Tassel	4	2	5	2	0	0	0	1	0	0	0	0
Silking	2	2	0	2	0	1	0	2	0	0	0	0
Blister	1	4	1	2	1	0	1	0	0	0	0	1
Blister	0	4	2	0	0	2	0	0	0	0	0	0
Dough	0	2	6	0	0	0	0	1	0	0	0	0
Dough	2	5	2	3	0	0	1	0	0	0	0	0
Dent	6	4	1	5	1	0	0	0	0	0	0	0

A = Atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.
B = Carbofuran 2.24 kg ai/ha + methomyl 0.5 kg ai/ha.
C = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha.
D = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.

Table 22. Ground arthropods, Selenophorus palliatus Fabricius (Carabidae), Conoderus scissus (Schffr.), and Conoderus amplicollis (Gyll.) (Elateridae), from pitfall traps in late planted field corn under different management strategies in Alachua Co., Florida, 1978.

Corn Growth Stage	Total Number of Specimens/Strategy											
	S. palliatus*				C. scissus*				C. amplicollis*			
	A	B	C	D	A	B	C	D	A	B	C	D
3-leaf	0	0	0	0	0	0	0	0	0	0	0	0
Early-whorl	0	0	0	0	362	82	45	25	0	0	0	0
Early-whorl	0	0	0	0	10	18	2	9	3	5	1	3
Mid-whorl	0	0	0	0	21	19	18	23	4	5	3	2
Mid-whorl	0	0	0	0	0	0	0	0	12	26	9	11
Late-whorl	0	0	0	0	0	0	0	0	31	37	28	14
Late-whorl	0	0	0	0	0	0	0	0	26	48	23	14
Tassel	2	4	0	2	0	0	0	0	12	24	20	16
Silking	0	4	0	4	0	0	0	0	3	7	3	0
Blister	10	6	14	12	0	0	0	0	9	43	18	21
Blister	17	314	292	25	0	0	0	0	55	34	37	9
Dough	132	216	381	161	0	0	0	0	12	15	23	14
Dough	256	174	68	393	0	0	0	0	20	13	17	15
Dent	100	173	418	287	0	0	0	0	11	26	30	19
Dent	243	295	417	490	0	0	0	0	61	37	41	66

*The collections were not significantly different at the 5% level.

A = Atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.
B = Carbofuran 2.24 kg ai/ha + methomyl 0.5 kg ai/ha.
C = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha.
D = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.

Table 23. Ground arthropods, Labidura riparia (Pallas) (Labiduridae) and Pardosa milvina (Hentz) (Lycosidae), from pitfall traps in late planted field corn under different management strategies in Alachua Co., Florida, 1978.

Corn Growth Stage	Total Number of Specimens/Strategy							
	L. riparia*				P. milvina*			
	A	B	C	D	A	B	C	D
3-leaf	19	6	8	4	0	0	0	0
Early-whorl	37	19	20	18	0	0	0	0
Early-whorl	68	57	51	74	0	0	0	0
Mid-whorl	46	56	71	70	0	2	0	0
Mid-whorl	569	803	691	660	1	0	5	0
Late-whorl	147	133	176	145	1	9	14	2
Late-whorl	251	271	228	254	5	5	8	5
Tassel	298	287	270	322	4	1	3	5
Silking	213	149	117	296	10	18	15	14
Blister	330	613	713	526	6	9	10	2
Blister	426	1458	922	670	3	0	4	1
Dough	646	1100	1010	641	0	0	2	0
Dough	860	1025	1170	1525	0	0	0	0
Dent	620	860	1358	1210	10	2	14	9
Dent	2025	2040	1780	1865	2	6	9	3

* The collections were not significantly different at the 5% level.

A = Atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.
B = Carbofuran 2.24 kg ai/ha + methomyl 0.5 kg ai/ha.
C = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha.
D = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.

Table 24. Ground arthropods from pitfall traps in early planted field corn, Coker 77: total numbers, percentage and rank of abundance, in Alachua Co., Florida, 1978.

Family/Species	Number of Specimens	% Total	Index
Carabidae			
Anisodactylus merula Germar	5	0.02	VR
Brachynus alternans Dejean	23	0.13	R
Calosoma externum Say	2	0.01	VR
Calosoma sayi Dejean	6	0.03	VR
Chlaenius erythropus Germar	5	0.02	VR
Colliurus pennsylvanicus (Linnaeus)	11	0.06	R
Evarthus morio Dejean	11	0.06	R
Galerita janus (Fabricius)	10	0.05	R
Galerita lecontei (Dejean)	17	0.09	R
Harpalus pennsylvanicus DeGeer	39	0.22	R
Pasimachus sublaevis Beauv.	2	0.01	VR
Pasimachus subsulcatus Say	4	0.02	VR
Selenophorus palliatus Fabricius	-	-	-
Cicindelidae			
Cicindela punctulata Oliv.	14	0.07	R
Megacephala virginica (Linnaeus)	14	0.07	R
Elateridae			
Conoderus scissus (Schffr.)	78	0.44	C
Conoderus amplicollis (Gyll.)	702	3.97	A
Labiduridae			
Labidura riparia (Pallas)	15570	81.98	A
Lycosidae			
Lycosa spp.	19	0.10	R
Pardosa milvina (Hentz)	1141	6.50	C
TOTAL	17647	100.00	

VR = Very rare, 10 specimens or less; R = rare, 11 to 50; C = common, 51 to 200; A = abundant, over 200.

Table 25. Ground arthropods from pitfall traps in late planted field corn, McNair 508: total numbers, percentage, and rank of abundance, in Alachua Co., Florida, 1978.

Family/Species	Number of Specimens	% Total	Index
Carabidae			
Anisodactylus merula Germar	8	0.02	VR
Brachynus alternans Dejean	8	0.02	VR
Calosoma externum Say	2	0.005	VR
Calosoma sayi Dejean	18	0.04	R
Chlaenius erythropus Germar	2	0.005	VR
Colliurus pennsylvanicus (Linnaeus)	7	0.01	VR
Evarthus morio Dejean	19	0.04	R
Galerita janus (Fabricius)	17	0.05	R
Galerita lecontei (Dejean)	22	0.05	R
Harpalus pennsylvanicus DeGeer	37	0.09	R
Pasimachus sublaevis Beauv.	7	0.01	VR
Pasimachus subsulcatus Say	13	0.03	R
Selenophorus palliatus Fabricius	4903	12.70	A
Cicindelidae			
Cicindela punctulata Oliv.	7	0.01	VR
Megacephala virginica (Linnaeus)	7	0.01	VR
Elateridae			
Conoderus scissus (Schffr.)	639	1.65	A
Conoderus amplicollis (Gyll.)	1027	2.66	A
Labiduridae			
Labidura riparia (Pallas)	31648	81.98	A
Lycosidae			
Lycosa spp.	1	0.002	VR
Pardosa milvina (Hentz)	208	0.53	C
TOTAL	38600	100.00	

VR = very rare, 10 specimens or less; R = rare, 11 to 50; C = common, 51 to 200; A = abundant, over 200.

Table 26. Seasonal abundance of Labidura riparia (Pallas), corn earworm, Heliothis zea (Boddie), and fall armyworm, Spodoptera frugiperda (J. E. Smith), in early planted field corn, Coker 77, grown under management strategy C, in Alachua Co., Florida, 1978.

Corn Growth Stage	Species		
	L. riparia	Fall armyworm	Corn earworm
	Mean Number/trap	% Infestation	% Infestation
3-leaf	2.66	0	0
Early-whorl	0.75	0	0
Early-whorl	2.75	0	0
Mid-whorl	9.75	0	0
Mid-whorl	8.50	2.8	0
Late-whorl	30.25	10.3	0
Late-whorl	30.25	20.0	0
Tassel	46.75	24.8	0
Silking	51.25	23.8	0.3
Blister	33.75	11.3	4.8
Blister	121.75	5.0	30.0
Dough	124.50	5.3	36.3
Dough	212.25	0	36.3
Dent	114.50	0	36.3
Dent	223.00	0	36.3

C = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha.

Table 27. Seasonal abundance of Labidura riparia (Pallas), corn earworm, Heliothis zea (Boddie), and fall armyworm, Spodoptera frugiperda (J. E. Smith), in late planted field corn, McNair 508, grown under management strategy C, in Alachua Co., Florida, 1978.

Corn Growth Stage	Species		
	L. riparia	Fall armyworm	Corn earworm
	Mean Number/trap	% Infestation	% Infestation
3-leaf	2.66	0	0
Early-whorl	6.66	0	0
Early-whorl	17.00	4.7	0
Mid-whorl	23.60	18.3	0
Mid-whorl	230.30	69.2	0
Late-whorl	58.66	90.2	0
Late-whorl	76.00	98.0	0
Tassel	90.00	100.0	0
Silking	39.00	3.6	9.2
Blister	237.66	4.0	42.2
Blister	307.33	0	88.0
Dough	336.66	0	91.2
Dough	390.00	0	91.2
Dent	462.66	0	91.2
Dent	593.33	0	91.2

C = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha.

Table 28. Rainfall and the population of Labidura riparia (Pallas) from pitfall traps in early and late planted field corn, Coker 77 and McNair 508, respectively, in Alachua Co., Florida, 1978.

Date	Rainfall mm	Mean Number of Earwigs	
		Early planted corn Coker 77	Late planted corn McNair 508
4/21/78	16.25	1.68	-
4/28/78	0	0.87	-
5/05/78	3.81	2.31	3.02
5/12/78	74.93	6.87	7.83
5/19/78	2.54	10.75	20.83
5/26/78	7.36	34.43	20.25
6/02/78	1.52	37.87	226.91
6/06/78	65.02	33.83	50.08
6/16/78	23.62	58.93	83.75
6/23/78	2.03	29.25	98.08
6/30/78	8.38	87.18	64.58
7/07/78	3.55	94.56	181.83
7/14/78	84.58	198.75	289.66
7/21/78	57.65	113.18	283.08
7/28/78	47.75	244.93	390.00
8/04/78	170.68	-	337.33
8/11/78	69.85	-	642.00

CHAPTER V

WEEDS IN FIELD CORN AND THEIR EFFECT ON CORN GROWTH UNDER DIFFERENT PEST MANAGEMENT STRATEGIES

Introduction

The presence of weeds in corn fields reduces corn growth due to competition for water, light, nutrients, and because of allelopathy (Larson and Hanway, 1977). Staniforth (1953) considered competition for light not serious because corn is a tall plant and few weeds can shade the plant. In fact, the shade provided by corn may help to determine the size of the competing weed. Competition for water and nutrients is very important to corn growth however. When weeds are present on corn fields, the removal of water from the soil and loss by plant transpiration is greatly increased. During dry weather, this process becomes evident and the corn plants show wilting symptoms and reduced growth. Similarly, soil nutrients are rapidly depleted from the soil by weeds, because they tend to accumulate far greater amounts of nutrients than corn (Behrens and Lee, 1966). The present study was conducted to monitor weeds in early and late planted corn as well as to determine the competitive effect on corn growth under different pest management strategies.

Materials and Methods

The research was conducted at Green Acres, University of Florida Experimental Station during the spring and summer, 1978. The materials and methods apply to both early and late planted field corn. The soil was characterized as fine sand lochloosa series (Standard Soil Survey Alachua Co. Florida, 1978). The hybrid Coker 77 was planted April 5 and McNair 508 April 28, respectively. In both plantings, the distance between plants was 20 cm in rows 91 cm apart. Both fields were fertilized before planting with 4-8-16 at 785.63 kg/ha and one sidedressing of ammonium nitrate at 112 kg/ha thirty days after planting.

A randomized block design was used for each planting date laid out over an area of 3416.64 m^2. Early planted field corn consisted of four treatments, each replicated four times. Each replicate was 8.80 x 12.12 m^2. Late planted corn had the same number of treatments but replicated three times. Each replicate was 10.92 x 12.12 m^2.

The treatments, hereafter called strategies, were as follows:

Strategy A. To control weeds and the complex of Heliothis-Spodoptera with pesticides. No treatment was made for soil pests. Atrazine at 1.12 kg ai/ha was applied postemergence

10 days after planting and before the corn was 12.7 cm tall. Methomyl, 0.5 kg ai/ha, was applied as needed to control Heliothis-Spodoptera.

Strategy B. To control soil pests and Heliothis-Spodoptera but not weeds. The soil was treated with carbofuran at 2.24 kg ai/ha. Methomyl, at the above rate, was applied as needed.

Strategy C. To control weeds and soil pests but not Heliothis-Spodoptera. The pesticides, rate and application time were those mentioned above.

Strategy D. To control weeds, soil pests and Heliothis-Spodoptera with the recommended pesticides. The rates, application time, and frequency were as described.

Weeds were monitored in herbicide untreated plots, strategy B. Weed density was established on each plot by counting the number of weed species on 1 m^2 (Klingman, 1973). The perimeter enclosed the weeds found in the row as well as those interrow. The area was staked out for further observations. Weed density was determined at treatment time and is expressed as number of each species/m^2.

Corn plant height was recorded weekly. Upon corn emergence from the soil, ten plants per replicate were measured, the height determined and expressed in centimeters. Percent growth reduction was established by comparing height averages of plants grown under strategy B and D. The measurements were recorded weekly until the corn plant reached the tassel stage.

Results

Atrazine was used to control weeds in both early and late planted field corn, Coker 77 and McNair 508, respectively. Weeds were not present in early planted field corn. Treated as well as untreated areas remained weed-free during the entire growing season. In late planted field corn, untreated plots, strategy B, favored weed growth. Atrazine-treated plots remained without weeds for most of the season. Weed density was measured in the row and between rows by determining the number of plants per square meter (Table 29). The following weed species were recorded: Florida pusley, Richardia scabra (L.); sicklepod, Cassia obtusifolia L.; goosegrass, Eleucine indica Gaertn. The densities were 62.5, 8.3, and 7.6 per square meter, respectively. During corn tasselling, two additional species were recorded in the corn system: crowfootgrass, Dactyloctenium aegyptium (L.) and Amaranthus sp. Weed density of each species was not recorded. Sicklepod grew taller than Florida pusley; Amaranthus outgrew all the weed species and sometimes the corn plant.

Corn plant height was recorded weekly on both corn systems (Table 30 and 31). In early planted corn, plant growth was uniform during the growing season. In late planted corn, plant growth was uniform from corn emergence through

the end of early-whorl stage. Thereafter, corn plants in non-herbicide plots showed reduced growth.

Discussion

The effect of weeds in early planted field corn, Coker 77, was minimal because they were not present in the corn system. Treated and untreated areas remained weed-free the whole season. The herbicide was applied following the recommended techniques and precautions. The application was carried out at 6:30 pm. It is not known what was the cause of this result. Probably some herbicide had already been incorporated into the soil.

In late planted field corn, the herbicide began to suppress weed growth five days after treatment; however, in the untreated plots, weed growth continued. The weeds initially observed when corn was in the 3-leaf stage continued to grow throughout the season. Weed density during early stages of corn growth, and duration of association between weeds and crop determine the effect of competition (Staniforth, 1953; Staniforth and Lovely, 1964). The effects of weed competition were observable at the end of the early-whorl stage of corn. During periods of low rainfall, wilt as well as plant yellowing was observed (Behrens and Lee, 1966) and corn plants were stunted. By the time the corn plant had reached the late-whorl stage, growth reduction

was about 40.1%. Retarded plant growth resulted from competition for water and nutrients (Larson and Hanway, 1977). The abnormal plant growth was exclusively attributed to the effect of weeds since growth reduction was observed only in herbicide untreated plots. The dominant weed species during early corn growth stages was Florida pusley. This species densely covered the ground (62.5 m^2) (Table 29). Late planted field corn probably withstood competition by weeds during early stages of growth. During advanced growth stages, however, it was unable to obtain nutrients and moisture sufficient to sustain growth.

Conclusions

Effects of weed competition in early planted field corn, Coker 77, were not measured because a weedy condition did not develop. Late planted field corn was affected by weeds. Five species were recorded: Richardia scabra, Cassia obtusifolia, Eleucine indica, Dactyloctenium aegyptium and Amaranthus sp. The dominant weed species was Florida pusley. At the densities at which this species was recorded in the corn system, the plant growth was reduced by 40.1%.

Table 29. Density of weed species found in late planted field corn, McNair 508.

Location	Average Number/m^{2*}		
	Florida pusley	Sicklepod	Goosegrass
Interrow	62.5	8.3	7.6
Inrow	29.0	3.6	1.6

*Based on average of 15 m^2.

Table 30. Average plant height in early planted field corn, Coker 77, under different pest management strategies, in Alachua Co., Florida, 1978.

Corn Growth Stage	Strategy/Plant Height cm.*			
	A	B	C	D
3-leaf	3.6	3.6	4.0	3.7
Early-whorl	9.9	10.0	10.0	9.9
Early-whorl	14.7	16.0	16.1	16.6
Mid-whorl	24.4	25.7	25.3	26.1
Mid-whorl	52.4	50.9	50.3	49.1
Late-whorl	71.7	72.3	73.2	68.9
Late-whorl	103.5	109.5	104.0	103.6
Tassel	121.9	122.9	119.0	127.9

* Average of 10 plants/replicate.

A = Atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.
B = Carbofuran 2.24 kg ai/ha + methomyl 0.5 kg ai/ha.
C = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha.
D = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.

Table 31. Average plant height in late planted field corn, McNair 508, under different pest management strategies, in Alachua Co., Florida, 1978.

Corn Growth Stage	Strategy/Plant Height cm.*			
	A	B	C	D
3-leaf	3.8	3.8	3.4	3.6
Early-whorl	6.8	6.6	7.3	6.5
Early-whorl	15.3	16.6	15.4	17.1
Mid-whorl	29.6	28.1	26.8	29.0
Mid-whorl	52.0	42.2	50.1	46.2
Late-whorl	96.2	77.0	100.0	96.6
Late-whorl	127.8	84.6	122.7	126.8
Tassel	158.4	97.6	157.0	163.0

*Average of 10 plants/replicate.

A = Atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.
B = Carbofuran 2.24 kg ai/ha + methomyl 0.5 kg ai/ha.
C = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha.
D = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.

CHAPTER VI

YIELD RESPONSE OF EARLY AND LATE PLANTED FIELD CORN TO DIFFERENT PEST MANAGEMENT STRATEGIES

Introduction

Damage sustained from the corn earworm, Heliothis zea (Boddie), and fall armyworm, Spodoptera frugiperda (J. E. Smith), has economic impact on corn production. Reviews by Luginbill (1928) and Isely (1935) present information on their effects for the early part of this century. During the 1950's, the corn earworm caused an estimated loss of $75 million (Blanchard and Douglas, 1953). In 1975, losses due to the fall armyworm and corn earworm accounted for $26,833,572 and $15,892,956, respectively (Georgia Entomological Society News Notes, 1976). In Illinois, a yield loss of 719 kg/ha has recently been recorded for the fall armyworm (Coop. Plant Pest Rep., 1978).

The effect of soil insect pest attack is conducive to several kinds of losses: reduced plant stand, replanting costs, overseeding to compensate for reduced plant stand, lodging and costs associated with control efforts (Kulash, 1947). Recently, in Illinois and Iowa, total losses due to soil pests have been estimated at $19,944,560 and $17,696,500, respectively (Sauer, 1974).

Corn parasitic nematodes have also been associated with yield reduction and investigations done to assess losses. This has been achieved by comparing yields of nematicide-treated with untreated plots and the result expressed as an average yield increase over the check (Rhoades, 1968, 1971, 1978; Johnson and Dickson, 1973; Kimpinski et al., 1977). Results of these experiments vary greatly. Kimpinski et al. (1977) reported no yield increase. Other authors have determined a yield increase from 21% (Norton et al., 1978) to 75% (Johnson and Dickson, 1973).

The presence of weeds in corn fields likewise reduces corn growth and yield (Larson and Hanway, 1977). Losses attributed to weed competition vary greatly. Staniforth (1953) observed an average yield reduction from 376 to 502 kg/ha. Hogan (1964) reported that weed control resulted in a yield increase of 2514 kg/ha. Moolani et al. (1964) established that weeds caused 39% yield reduction. Research conducted at Minnesota indicated that corn yield reduction due to weeds ranges from 16 to 93% (Behrens and Lee, 1966).

The data reported here were obtained from an experiment to determine the effects of management strategies in early and late planted field corn, Coker 77 and McNair 508, respectively.

Materials and Methods

The research was conducted at Green Acres, University of Florida Experimental Station during the spring and summer, 1978. The materials and methods apply to both early and late planted field corn. The soil was characterized as fine sand lochloosa series (Standard Soil Survey Alachua Co. Florida, 1978). The hybrid Coker 77 was planted April 5 and McNair 508 April 28. In both plantings, the distance between plants was 20 cm in rows 91 cm apart. Both fields were fertilized before planting with 4-8-16 at 785.63 kg/ha and one sidedressing of ammonium nitrate at 112 kg/ha thirty days after planting.

A randomized block design was used for each planting date laid out over an area of 3416.64 m^2. Early planted field corn consisted of four treatments, each replicated four times. Each replicate was 8.80 x 12.12 m^2. Late planted corn had the same number of treatments but replicated three times. Each replicate was 10.92 x 12.12 m^2.

The treatments, hereafter called strategies, were as follows:

Strategy A. To control weeds and the complex of Heliothis-Spodoptera using pesticides. No treatment was made for soil pests. Atrazine, at 1.12 kg ai/ha, was applied postemergence

10 days after planting and before the corn was 12.7 cm tall. Methomyl, 0.5 kg ai/ha, was applied as needed to control Heliothis-Spodoptera.

Strategy B. To control soil pests and Heliothis-Spodoptera but not weeds. The soil was treated with carbofuran at 2.24 kg ai/ha. Methomyl, at the above rate, was applied as needed.

Strategy C. To control weeds and soil pests but not Heliothis-Spodoptera. The pesticides, rates, and application time were those mentioned above.

Strategy D. To control weeds, soil pests and Heliothis-Spodoptera with the recommended pesticides. The rates, application time, and frequency were as described.

The total plant response to the different pest management strategies was measured by determining yields. The ears of 100 plants per replicate in each strategy were harvested, dried, shelled and the grains weighed to establish yield.

Results

In early planted field corn (Table 32), fully protected plants, strategy D, resulted in the highest average yield but the difference was not significant. Comparisons between fully and partially protected plants indicated that the elimination of any needed protection resulted in average yield reduction. The lack of control of the fall armyworm-corn

earworm reduced yield by 18.2%. Likewise, the absence of weed control, strategy B, resulted in a 7.7% loss; the soil-pest complex, strategy A, reduced yield by 1.2%. The analysis of variance did not detect significant differences at the 5% level among the mean yields of fully and partially protected plants. The impact of pests on early corn was minimal compared to their effect on late planted corn; hence, differences measured were not significant.

In late planted corn (Table 33), corn yield response was more or less similar to that of early planted corn. The use of all protective herbicides, soil and foliar pesticides, strategy D, achieved the highest corn yield. The fall armyworm-corn earworm, in the absence of foliar insecticide compared to fully protected plants, reduced yield by 37.2%. The lack of weed and soil pest control resulted in 57.9 and 10.2% yield reduction, respectively. There were significant differences at the 5% level among mean yields from plants grown under the different pest management strategies (Table 33).

Mean yield in strategy D was significantly different from the yields in strategies B or C. Likewise, the mean yield in strategy A differed from those in strategy A or B. The result indicates that both weeds and fall armyworm-corn earworm greatly influenced the yield response of corn. Control of both pests was necessary to prevent losses (Table 33). The mean yield in strategy A which controlled weeds and the complex Heliothis-Spodoptera did not significantly

differ from the yield in strategy D where weeds, soil and foliar pests were controlled. This suggests that there was no difference between maximum plant protection and the lack of soil pest control. Soil pests probably were not a serious problem. Similarly, there were no significant differences between the mean yields in strategy B and C. The result indicates that corn yield could be equally affected by the absence of weeds or fall armyworm-corn earworm control.

Complete plant protection, strategy D, resulted in the highest yield, regardless of planting date (Table 32 and 33). In the absence of control, the fall armyworm-corn earworm resulted in 18.3 and 37.2% yield reduction. In the absence of weed control yields were reduced by 7.7 and 57.7%. Soil pests decreased yield by 1.2 and 10.2%, in early and late planted corn, respectively. In general, yield losses were more difficult to prevent in late than early planted corn.

Discussion

Strategy A was designed to control weeds and the complex Heliothis-Spodoptera, but no treatment was made for soil pests. The strategy estimated indirectly the effect of soil pests on corn yield when the fall armyworm-corn earworm were controlled with methomyl and atrazine, respectively. Soil insect pests were not present in corn of either planting date. The absence of soil pests even where no treatments were

applied did not permit the study of the effect of these pests on corn production, nor the action of carbofuran on soil insect pests. Heavy population levels of Pratylenchus spp. and Meloidogyne spp. infested the roots of both early and late planted corn. Nematode populations were significantly different among the strategies in early planted corn but not in late planted corn (Table 14).

The effects of carbofuran on the corn plant and soil pests are not well known. Carbofuran was reported as a growth and yield stimulant on corn (Apple, 1971). It has suppressed soil pests (Turpin, 1974b; Baranowski and Waddill, 1975), but in other situations has failed to control the same insect species (DuRant, 1975; All and Jellum, 1977). The mode of action on nematodes was discussed by Di Sanzo (1973). Nematode control with carbofuran has not always achieved positive yield response on corn (Kimpinski et al., 1977), and nematodes are often found in carbofuran treated plots. Yield response was probably affected by the presence of nematodes in both corn systems. High numbers of nematodes do not always directly contribute to yield loss, however. Nematode numbers have been negatively correlated with yield (Norton et al., 1978). Nematode populations were significantly different in early planted corn but the overall yield responce was not. The lack of significance may indicate that the nematodes either equally affected yield response or had no measurable effect at all. Carbofuran stimulative effect (Apple, 1971) could also have affected the results herein presented.

The application of carbofuran in this study was considered as an insurance or preventive application (Peters, 1975). The treatment was made without any evidence of soil pests in the corn system. Prophylactic use of soil insecticides has seldom been profitable in other areas (Turpin and Thieme, 1978). Preventive applications of pesticides do not generally fit the strategy schemes of integrated management for pest populations where therapeutic treatments can be instituted.

Yield response of corn protected under strategy A indicated that, under the conditions of this study, soil pest control was not as important as the other management strategies used to prevent yield reduction.

Strategy B was designed to control soil pests and the complex Heliothis-Spodoptera, but no treatments were made for weeds. The strategy was used to estimate indirectly the effect of weed competition on corn yield when the fall armyworm-corn earworm and soil pests were controlled with methomyl and atrazine, respectively. The net effect of weed competition in early planted corn was not measured because treated and untreated replicates remained weed-free throughout the study period. In late planted corn, three weed species, Richardia scabra (L.), Cassia obtusifolia L. and Eleucine indica Gaertn., were associated with corn during most of the growing season. In competition with these weed species, corn growth was reduced by 40.1% (Table 31).

Corn yield was affected by weeds despite the use of fertilizer and protective pesticides (Table 32 and 33).

The effects of weed competition were more visible in later stages of corn growth. The corn plant's general physical appearance was diminished by yellow leaves and wilt. Corn competition with weeds lasted from the 3-leaf stage through corn maturity. The longlasting effect was crucial to the corn plant (Staniforth, 1953; Staniforth and Lovely, 1964). The stress factors caused by weed competition were associated with the crop long enough to reduce plant growth by 40.1% and yield by 57.9%.

Yield response of corn grown with or without herbicides indicated that, under the conditions of this study, weed control was extremely important to corn production. The lack of weed control resulted in loss of yield.

Strategy C was designed to control weeds and soil pests but not Heliothis-Spodoptera. The strategy was used to estimate indirectly the effect of fall armyworm-corn earworm on corn yield. The fall armyworm and corn earworm were found infesting early and late planted corn; however, infestation levels and leaf damage pattern were higher in late than early planted corn (Table 4 and 9).

Yield response of corn grown under strategy C was affected by two factors: planting dates and fall armyworm-corn earworm infestations. In early planted corn, the lack of fall armyworm-corn earworm control resulted in infestation levels of 24.8 and 36.3%, respectively (Table 4). These insects caused leaf and ear damage. The combined effect of both types of damage resulted in 18.3% yield reduc-

tion from the maximum-protected plants. Planting dates probably influenced yield response in this study. Previous investigators concluded that early planting promotes yield response (Lutrick, 1964; Pendleton and Egli, 1969) and reduces chances for pest attack (McColloch, 1924). Since planting date favored yield response, the reduction was attributed to the effect of fall armyworm-corn earworm infestations. At an average price of $2.00/25.45 kg, this economic loss accounted for $104.40/ha.

Similarly, in late planted corn, the absence of treatments to control fall armyworm and corn earworm resulted in plant infestation levels of 100 and 91.2%, respectively (Table 4). Planting date was probably the decisive factor determining corn yield response to these pests. Planting time affected both the host and the fall armyworm-corn earworm populations. Delay in corn planting is known to reduce corn yield and increase pest incidence on corn (Everly, 1961; Chiang and Hodson, 1963). Late planting favored the incidence of fall armyworm on corn. Fall armyworm-corn earworm infestation level was higher than that recorded for early planted corn and was undoubtedly highly damaging to foliage and corn ears. Together the loss of photosynthetic area and ear damage caused 37.2% reduction in yield. At an estimated price of $2.00/25.45 kg, this loss accounted for $159.36/ha.

Lack of fall armyworm-corn earworm control resulted in 18.2 and 37.2% yield reduction, in early and late planted

corn, respectively. No chemical control is usually carried out on those pests because of the low economic return of the crop (Chiang, 1978). Under normal farming operation conditions, economic losses of $104.40 and $159.36 per hectare are probably likely to occur in Florida field corn.

Strategy D was designed to control weeds, soil pests, and fall armyworm-corn earworm. The strategy was considered as a pattern to be used in indirectly measuring the complex action of fall armyworm-corn earworm, soil pests and weeds on the yield response of field corn. Yield response of corn grown under full protection, strategy D, resulted in the highest yield, regardless of planting date. In early planted field corn, the lack of control of weeds, soil pests and the complex fall armyworm-corn earworm resulted in yield reduction. The total economic loss by the three pest groups was $155.06/ha. Similarly, in late planted corn, the economic loss was $441.42/ha. Despite the use of the same protective pesticides, rates, and application methods, yield reduction was more difficult to prevent in late than in early planted corn.

Conclusions

Four pest management strategies were used to determine yield response in early and late planted corn, Coker 77 and McNair 508, respectively. In early planted field corn, the

lack of soil pest control caused an economic loss of $6.64/ha; weeds, $44.02/ha; and fall armyworm-corn earworm, $104.40/ha. The cumulative loss was $155.06/ha. In late planted field corn, the lack of soil pest control resulted in an economic loss of $42.16/ha; weeds $239.90/ha; and fall armyworm-corn earworm $159.36/ha. The cumulative loss was $441.42/ha. Lack of soil pest control was not as important as the control of the other pest groups. It is evident that weed control followed by fall armyworm-corn earworm control were essential to protect plant yield, regardless of planting date. Fall armyworm-corn earworm and weed control were the most important components in corn production. These pest groups caused yield reduction in both early and late planted corn. Pest situations and yield reduction were more serious in late than in early planted corn.

Table 32. Yield response of early planted field corn, Coker 77, to plant protection strategies in Alachua Co., Florida, 1978.

Strategy	Yield kg/ha			Economic loss
	Mean	Reduction	% reduction	$/ha
A	4730.0a	536.6a	10.2	42.16
B	2213.7b	3052.7b	57.9	239.90
C	3307.4b	1959.2b	37.2	159.36
D	5256.6a	0.0a	0.0	0.00
TOTAL				441.42

Means with the same letter are now significantly different.

A = Atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.
B = Carbofuran 2.24 kg ai/ha + methomyl 0.5 kg ai/ha.
C = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha.
D = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.

Table 33. Yield response of late planted corn, McNair 508, to plant protection strategies in Alachua Co., Florida, 1978.

Strategy	Yield kg/ha			Economic loss
	Mean	Reduction	% reduction	$/ha
A	4730.0a	536.6a	10.2	42.16
B	2213.7b	3052.7b	57.9	239.90
C	3307.4b	1959.2b	37.2	159.36
D	5256.6a	0.0a	0.0	0.00
TOTAL				441.42

Means with the same letter are now significantly different.

A = Atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.
B = Carbofuran 2.24 kg ai/ha + methomyl 0.5 kg ai/ha.
C = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha
D = Carbofuran 2.24 kg ai/ha + atrazine 1.12 kg ai/ha + methomyl 0.5 kg ai/ha.

APPENDIX

Table 34. Weekly temperature and rainfall for the 1977 corn growing season*

Date	Average Temperature** °C	Rain mm
3/17-3/22	24.41	4.06
3/23-3/29	18.33	0
3/30-4/05	23.76	5.80
4/06-4/12	18.09	0
4/13-4/19	21.26	0
4/20-4/26	22.77	16.00
4/27-5/03	20.15	0
5/04-5/10	25.99	5.84
5/11-5/17	22.81	0
5/18-5/24	24.44	0.25
5/25-5/31	25.39	5.58
6/01-6/07	27.53	9.39
6/08-6/14	28.37	0
6/15-6/21	28.57	32.52
6/22-6/28	28.84	14.47
6/29-7/05	27.81	12.44
7/06-7/12	28.69	8.63
7/13-7/20	28.92	3.81
7/21-7/26	28.88	0
7/27-8/02	28.76	12.95

* Adapted from data: Agronomy Department and NOAA Cooperating.

** Ambient temperature at 1.52 m.

Table 35. Monthly temperature and rainfall: averages for 1977 and records of 70 years*

Month	Temperature °C Ambient**		Soil**	Rain mm	
	1977	70 years	1977	1977	70 years
January	9.05	14.27	11.88	85.09	72.13
February	12.47	15.22	12.88	105.66	93.90
March	20.40	18.00	19.97	30.98	108.20
April	20.72	20.94	22.08	21.08	76.70
May	24.47	24.16	25.27	11.68	89.91
June	28.38	26.52	28.47	57.40	172.29
July	28.61	27.11	29.38	36.57	203.96
August	28.08	27.27	28.61	180.34	209.55

*Adapted from data in: Agronomy Department and NOAA.

**Ambient temperature at 1.52 m; soil at 10.16 cm depth under centipede grass.

Table 36. Weekly temperature and rainfall for the corn growing season during 1978*

Date	Temperature °C ambient	Rainfall mm
4/05/78	19.52	0
4/12/78	23.25	0
4/19/78	22.50	16.25
4/26/78	20.19	0
5/03/78	19.72	3.81
5/10/78	24.44	74.93
5/17/78	23.05	2.54
5/24/78	25.59	7.36
5/31/78	25.95	1.52
6/07/78	25.95	65.02
6/14/78	27.69	23.62
6/21/78	26.03	2.03
6/28/78	27.93	8.38
7/05/78	29.00	3.55
7/12/78	27.18	84.58
7/19/78	26.98	57.65
7/26/78	28.00	47.75
8/02/78	26.00	170.68
8/09/78	27.34	69.85
8/16/78	27.14	61.77

* Adapted from data in: Agronomy Department and NOAA Cooperating.

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BIOGRAPHICAL SKETCH

Saul Edgardo Contreras Galvez was born January 3, 1940, in Coatepeque, Depto Santa Ana, El Salvador. He graduated from Liceo Santaneco (High School) in 1957. He attended the University of El Salvador 1959-1965 and received the degree of Ingeniero Agronomo (Agricultural Engineer) October 21, 1965. He entered the Graduate School of Texas A. and M. University and pursued his work toward a M. Sc. degree in Entomology which was awarded May 8, 1971. Since January 1976, he has been a graduate student at the Entomology and Nematology Department, University of Florida.

While earning his Agricultural Engineer degree at the University of El Salvador, he was employed by the Facultad of Ciencias Agronomicas and worked as Laboratory Technician from 1962-1965. He then was Assistant Professor from 1965-1968. He then was the Head of the Department of Parasitology from 1971-1975.

While being a student at the University of El Salvador, he was given Scholastic awards during 1962, 1963, 1964, and 1965. He was awarded two scholarships, from the University of El Salvador and Rockefeller Foundation, to pursue graduate work at Texas A. and M. University and University of Florida, respectively.

His experiences include nematode research on field crops, and pest control on coffee, cotton, and corn.

He married the former Martha Alicia Lopez in August 1959, and they have four children, Erick Jose, Mauricio Eduardo, Saul Edgardo, Jr., and Liza Carolina.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

S. L. Poe, Chairman
Professor of Entomology

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D. H. Habeck
Professor of Entomology

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R. I. Sailer
Professor of Entomology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

F. W. Zettler
Professor of Plant Pathology

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

June 1979

Jack L. Fry

Dean, College of Agriculture

Dean, Graduate School